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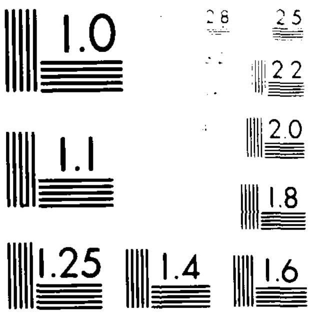
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AIDS TO NAVIGATION PRINCIPAL FINDINGS REPORT ON THE CHANNEL WIDTH EXPERIMENT: THE EFFECTS OF CHANNEL WIDTH AND RELATED VARIABLES ON PILOTING PERFORMANCE

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Interim Report

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16. Abstract

The experiment described here is one of a series done for the U.S. Coast Guard to quantify the relationship between variables related to aids to navigation and piloting performance in narrow channels and, potentially, safety in such channels. This is one of several experiments restricted to visual piloting, and further to buoys only. It was done on a simulator built for the U.S. Coast Guard at Eclectech Associates in North Stonington, Connecticut. The variables evaluated were: straight channel marking (staggered versus gated buoys), spacing (5/8 versus 1-1/4 nm), channel width (500 versus 800 feet), and intended track (center versus right-hand quarter). Tasks and current effects were varied within the scenario. The findings are presented as the means and standard deviations of crosstrack position of transits under each condition. They are interpreted in terms of their implications both for the design of channel marking and for an understanding of the piloting task. A secondary purpose of the experiment was the comparison of performance on the USCG/EA simulator and on CAORF, the Maritime Administration's Computer Aided Operations Research Facility.

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METRIC CONVERSION FACTORS

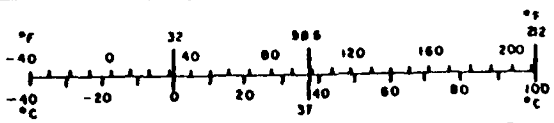
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

The experiment described here is a component of the United States Coast Guard's Performance of Aids to Navigation Systems project. This project is meant to collect the data necessary to lead to guidelines for the design of AN Systems. The project includes (or will include) a survey of U.S. ports to summarize existing conditions; a survey of relevant variables to be considered; a major simulator Ship Variables experiment in visual piloting done at Maritime Administration's Computer Aided Operations Research Facility (CAORF) in New York; four visual piloting (SRAN) and three radio aids piloting (RA) experiments done at a simulator developed for the project at Eclectech Associates, Inc., in North Stonington, Connecticut; and an at sea data collection to provide validation of the USCG/EA simulator and the experimental results. The final step will be the preparation of the overall findings for the development of design guidelines.

The experiment described here is the first of four visual piloting experiments done on the USCG/EA simulator. Visual aids in this experiment were restricted to large, lighted buoys. The experiment evaluated the effect of channel width on piloting performance both in isolation and in combination with such related factors as environmental conditions, piloting tasks, and aid number and placement. The following is a summary of conclusions supported by the experiment.

- A channel must be marked for the most demanding task to be required: trackkeeping or maneuvering, with or without perturbation.

- For a wide (800-foot) channel, a variety of buoy arrangements support adequate performance.

- For a narrow (500-foot) channel, both number and placement of buoys have effects. Gated, short-spaced arrangements are optimum. Gated arrangements can be increased in spacing with less deleterious effects on performance than can staggered. Staggered, long-spaced arrangements result in inferior performance.

- The arrangement of buoys influences the pilot's choice of strategy as well as his achievement of that strategy. A large number of well-placed buoys allows a choice of an effective strategy. A low number of poorly-placed buoys forces a pilot to rely on less effective strategies.

- For the purpose of evaluation of differences or relationships between alternative aid arrangements, the two simulations - CAORF and USCG/EA - appear to be functionally the same.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to CAPT J.T. Montony of the United States Coast Guard for his continued personal participation in the project. We would also like to thank CDR J.F. Roeber and LT John Anthony for their contributions. We are grateful to Mr. Karl Schroeder for his continuing help and support.

The authors would like to thank CAPT D.G. Leonard, President of Northeast Marine Pilots, Inc., for his cooperation. We want to thank the other members of the association for serving as experimental subjects. We especially want to thank them all for their comments on the simulation, during this, the first visual experiments done on the USCG/EA simulator.

EXECUTIVE SUMMARY

INTRODUCTION

The objective of the project to which this simulator experiment contributed was the methodical evaluation of variables expected to affect piloting in restricted waterways. These included variables describing ship characteristics, the physical characteristics of channels and turns, environmental conditions, and, most centrally, the characteristics of aids to navigation. The present experiment is one of several designed to examine visual piloting, and more specifically, piloting with buoys. Later experiments will broaden the investigation to include fixed aids, and, finally, radar.

The first simulator experiment in the series was done at CAORF, the Maritime Administration's Computer Aided Operations Research Facility in New York. The present experiment was done at a simulator built for this U.S. Coast Guard project by Eclectech Associates in North Stonington, Connecticut.

The experiment to be described here evaluated two new variables: channel width (500 versus 800 feet) and intended track (centerline versus right-hand quarter of the channel). To increase the generality of the findings, the two variables previously evaluated and found to affect the process in straight channel segments were also included: straight channel marking (staggered versus gated) and spacing (5/8 versus 1-1/4 nm). A secondary issue was a functional comparison of CAORF and the USCG/EA simulations to ensure the ability to proceed in this research program. The two simulations were compared using both an interaction – straight channel marking by spacing – and individual scenarios selected to be comparable.

SUMMARY OF THE FINDINGS

1. Straight channel marking by spacing. This second simulation experiment replicated a principal finding of the earlier one: in 500-foot channels, gated buoys led to more precise performance than staggered buoys; short spacing (5/8 nm) led to more precise performance than long (1-1/4 nm). The interaction was such that the effectiveness of staggered buoys was more dependent on spacing than that of gated.

The replication of this interaction demonstrated the similarity of the two simulations.

2. Channel width. Increasing the width of the channel from 500 to 800 feet increased the width of the band of transits. However, this increase was not proportional to the greater space available. This was true whether the buoy were gated or staggered. Therefore, wide channels are not a special piloting or design or research problem.

Marking adequate for narrow channels is adequate for wider channels – and may be more than is necessary.

3. Intended track. Changing the intended track from the centerline to the right-hand quarter of an 800-foot channel, of necessity, resulted in a band of transits closer to the right-hand edge of the channel. However, there seemed to be a compensating increase in certainty about the location of that edge. This was true

whether the buoys were staggered or gated. Therefore, the right-hand transits are not a special piloting or design or research problem.

Marking adequate for a centerline is adequate for a right-hand track.

IMPLICATIONS FOR AIDS TO NAVIGATION SYSTEM DESIGN

1. The process of marking a channel must begin with the performance requirements for that channel. Marking must be planned for the most demanding task to be required in that channel or channel segment: trackkeeping or maneuvering, with or without perturbation.

2. Channel width is a factor. With a wide channel (800 feet), a variety of channel markings are acceptable. With a narrower channel (500 feet), greater precision is necessary and marking is more critical.

3. When precision is important in narrow channels (500 feet), gated, short-spaced (5/8 nm) marking has demonstrated an advantage.

4. When the pullout from a turn is made into a narrow channel (500 feet), there is an advantage to gated configurations.

5. Assuming that two-way traffic is allowed only in wide channels (800 feet), a variety of markings are acceptable.

INTERPRETATION IN TERMS OF THE PILOTING TASK

1. Determination of the strategy. Early in this project, it was assumed that the first three classes of variables – ship characteristics, channel characteristics, and environmental factors – determined the nature of the piloting task or the strategies selected by the pilot. The fourth class of variables – placement of aids to navigation – was assumed to "aid" the pilots in accomplishing that task. This proved to be an oversimplification of the process. Close inspection of the pilots' behavior with staggered or gated, long- or short-spaced buoys suggests that the placement of the aids contributes to the problem or to the determination of the strategy used. As an example, long-spaced, staggered buoys (and, presumably, any irregularly-placed buoys) lead some pilots to "buoy-hop" or "zigzag."

The placement of aids will affect choice of strategy as well as ability to achieve a chosen strategy.

2. Interpretation of the performance measures. At the start of the project, it was assumed that the mean of a group of transits represented the intended-track or strategy and the standard deviation represented the groups' ability to achieve that track or strategy under given buoy conditions. Instead, in some conditions, the observed mean and standard deviation represents a pooling of more than one strategy. That the pilots differed in intended track may be inferred when inspection of the data reveals two (or more) clusters of tracks, each with a small standard deviation. A large standard deviation may mean that the aids were so good that some pilots felt free to use less conservative strategies.

Good buoy information (in this case, gated buoys and short spacing) may lead to a variety of strategies rather than to better performance of one strategy.

THE SIMULATION COMPARISON

Performance observed with the two simulations – CAORF and USCG/EA – showed similar patterns of differences among trackkeeping and maneuvering portions with and without perturbations within the scenario; and among long- and short-spaced staggered and gated configurations between scenarios. A comparison of absolute values was impossible to address due to subject differences, system subleties, and experimental design incompatibilities. Future research will address this comparison along with at-sea data in series of validation and calibration experiments.

For the purpose of evaluation of differences or relationships between alternate AN configurations, the two simulations – CAORF and USCG/EA – appear to be functionally the same.

SUGGESTIONS FOR FUTURE RESEARCH

An understanding of how pilots use buoy information is helpful in planning future experiments: that is, in selecting variables to be combined into meaningful experiments.

1. One-sided buoy configurations. In this experiment, pilots transiting the right-hand side of a channel showed a tendency to concentrate on the close-side buoys and to do better when the current forced them closer to those buoys. This suggests that an important factor would be the closeness of the single line of buoys. This could be varied by changing the width of the channel, the intended track, or the direction of the current. Piloting with staggered buoys seems to make greater use of buoys to the side and is aided by decreasing spacing. This suggests that unfavorable one-sided conditions might be mitigated by decreased spacing.

2. Two-way traffic in turns. The three-buoy turns used in this experiment included an inside turnpoint buoy and two outside buoys some distance from the outside apex of the turn. The observed tendency to concentrate on the close buoys when not at the center of the channel suggests that the outside turn apex should be marked in wide turns where vessels are expected to meet in the turn.

3. Ranges. When the pilots were transiting the center of a narrow channel, they showed a tendency to locate the center of the channel up ahead using buoys on both sides; when they were transiting the right-hand quarter, they tended to concentrate on the right-hand edge and the right-hand buoys only. This suggests that transiting the right-hand quarter of a channel would be difficult with a range marking the center.

4. "Perfect information." The condition with the most buoy information in this experiment included three buoys in the turn and short-spaced (5/8 nm) gated buoys in the straight segments. The pilots' precision in keeping to instructed strategy for most of the scenario, and their apparent confidence in choosing a greater variety of strategies when allowed to do so in the turn, suggest that this condition contains as much information as can be used in piloting with buoys. Their use of alternative strategies in high buoy information conditions must be inspected for "over-control," or an excessive number of helm orders that perturb the ship.

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Section 1
INTRODUCTION

1.1 AN OVERVIEW OF THE AIDS TO NAVIGATION PROJECT

The United States Coast Guard is responsible for safety in U.S. harbors and channels and, therefore, for the aids to navigation (AN) necessary to ensure that safety. It is in fulfillment of this responsibility that the Coast Guard is sponsoring a simulator-based program of research into the performance of aids to navigation. Interests include visual aids to navigation, radar navigation, and radio aids. To reduce the problem of evaluating visual aids to navigation to workable size, the first visual experiments were restricted to buoys. Later plans are to expand the evaluation to ranges and to leading lights and, eventually, to radar. The first of the buoy experiments is available as a separate report[1] and is reviewed briefly in Section 1.2 below. The planning of the second such experiment is described in the Channel Width Presimulation Report.[2] The result of that experiment is the principal topic of this paper. A description of a related experimental project on radio aids is also available.[3,4] The final objectives of the project are the use of experimental data to derive design criteria for the placement of aids to navigation and to specify radio aids to navigation systems for narrow channels with turns.

Two support studies were done to guide the research. The first of these studies was a survey of the characteristics of channel design and present aids to navigation in 32 major U.S. ports to determine the conditions to be represented in the experiment. The inclusion in the experiment of frequent conditions maximizes the usefulness or generality of the findings from necessarily limited experimentation. Some findings from the survey are excerpted in Section 1.3 below. That study is available as a separate report.[5] The second support study was a review of factors expected to have meaningful effects on navigation performance in narrow channels

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[1]M.W. Smith and W.R. Bertsche. Aids to Navigation Report on the CAORF Experiment. The Performance of Visual Aids to Navigation as Evaluated by Simulation. U.S. Coast Guard, Washington, D.C., August 1980.

[2]M.W. Smith. Aids to Navigation Presimulation Report: The Effects of Channel Width and Related Variables on Piloting Performance. U.S. Coast Guard, Washington, D.C., July 1980.

[3]R.B. Cooper and K.L. Marino. Simulator Evaluation of Electronic Radio Aids to Navigation Displays. U.S. Coast Guard, Washington, D.C., March 1980.

[4]Eclectech Associates. Presimulation Plan for the Evaluation of Radio Aids to Navigation Displays Without System Noise. U.S. Coast Guard, Washington, D.C., April 1980.

[5]W.R. Bertsche and R.T. Mercer. Aids to Navigation Configurations and the Physical Characteristics of Waterways in 32 Major U.S. Ports. U.S. Coast Guard, Washington, D.C., October 1979.

and turns typical of harbor waterways. These factors, describing ship characteristics, physical characteristics of channels and turns, environmental conditions, and characteristics of aids to navigation, are listed in Table 1. The first three categories of variables define the difficulty of the piloting problem, while the last defines the "aid" that is available for solving it. The difficulty of the problem and the adequacy of the available aids together determine the piloting performance observed. The table also identifies the variables included in the experiments planned or completed. This review is also available as a separate report.[6]

The first simulator experiment on floating aids to navigation was conducted at CAORF, the Maritime Administration's Computer Aided Operation Research Facility in New York. The second, the one to be described here, was conducted at a simulator built for this U.S. Coast Guard project by Eclectech Associates in North Stonington, Connecticut. Both are bridge simulators, which provide the bridge, the ship hydrodynamics, the environmental effects, and the visual scene necessary for this series of experiments. A comparison of the results obtained on the two is discussed in Section 3.

TABLE 1. NAVIGATION PROCESS VARIABLES

	Experiment
Ship	
Perspective view	Ship
Speed	Ship
Maneuverability	Ship
Channel dimensions	
Banks	
Width	Channel Width
Turn angle	CAORF
Turn radius (configuration)	CAORF
Enviromental factors	
Current/wind	CAORF, Channel Width
Day/night	CAORF
Visibility/detection distance	CAORF
Traffic ships	CAORF
AN placement	
Spacing	CAORF, Channel Width
Straight channel marking	CAORF, Channel Width
Flash period	
Turnmarking	CAORF

[6]W.R. Bertsche and R.C. Cook. Analysis of Visual Navigational Variables and Interactions, Interim Report. U.S. Coast Guard, Washington, D.C., October 1979.

1.2 DEVELOPMENT OF THE EXPERIMENTAL METHODOLOGY DURING THE CAORF EXPERIMENT

As the second in a series, the Channel Width Experiment benefited from the planning and evaluation of the first, CAORF, experiment. The two experiments used very similar methodology. Because of this, the second experiment can be understood as a continuation of the first. Conditions remaining constant between the two allow comparisons; at the same time conditions that differ between them extend the understanding of the relationships between aids to navigation and piloting performance.

The following points describe the general methodology developed in the first experiment and carried over to the second.

1. The simulation method. The process involving the four classes of variables (listed in Table 1) and piloting as practiced by licensed harbor pilots is so complex as to require real-time simulation for its evaluation. Any analysis of the task into components would risk loss of validity and generalizability to real-world events.

2. A varied scenario. The performance or adequacy of aids to navigation depends on the demands of the piloting task with which that performance is evaluated. The scenarios used in both experiments included both maneuvering and trackkeeping, both with and without perturbation.

3. The performance measures. The earlier experiment included the evaluation of a variety of performance measures. The principal measure for the present experiment was the crosstrack position of the ship's center of gravity as it transited the channel. Plots were prepared showing the band formed by the mean of these transits with two standard deviations to either side against the outline of the channel. Such a band encompasses 95 percent of the expected experimental runs under any condition. It is a graphic means of comparing sets of conditions.

In addition to the developed methodology, the Channel Width Experiment benefited from the empirical findings of the CAORF Experiment. These points contributed most directly to the planning of the second experiment.

1. Turnmarking. Performance on even a difficult turn is sufficiently aided by three buoys marking that turn to allow comparison of straight channel conditions beyond that turn. The present experiment included only one turn: a difficult 35-degree noncutoff turn marked by three buoys.

2. Straight channel marking. The configuration of the buoy arrangement affects the precision of observed piloting performance; generally, gates are better than staggered buoys. Spacing (5/8 nm versus 1-1/4 nm) was also a factor, more so with staggered than with gated buoys. Because the findings of the first experiment suggested that buoy configuration had a major effect on the piloting process, this later experiment continued to vary these conditions.

A more complete discussion of that experiment is available separately.[7]

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[7]Smith and Bertsche.

1.3 THE EXPERIMENTAL CONDITIONS FOR THE CHANNEL WIDTH EXPERIMENT

The primary purpose of the Channel Width Experiment was the extension of the understanding of visual piloting begun in the CAORF Experiment. For this purpose, channel width was varied – 500 and 800 feet – in a context of other relevant variables. The eight scenarios in the experiment permitted the three sets of comparisons outlined in Figure 1 and described below. (Diagrams of these eight scenarios appear as Appendix A.) A secondary purpose was a comparison between the two simulations – CAORF and USCG/EA. This comparison is discussed in Section 3.

1. The Replication of the Straight Channel Marking by Spacing Interaction. The first four scenarios selected were the combinations of staggered and gated buoys and 5/8 nm and 1-1/4 nm spacing. They are Scenarios 1 to 4 in Figure 1. This was a key interaction of the CAORF experiment.

2. Straight Channel Marking by Channel Width. The two 1-1/4 nm spaced scenarios in the first two-way comparison were re-used along with two new scenarios that differed from them in channel width: 800 feet rather than 500 feet. These are Scenarios 3 to 6 in Figure 1. This was a screening experiment for the one variable of channel width. It was meant to answer the entirely empirical question: what happens to the mean and standard deviation of crosstrack position when channel width is increased from 500 to 800 feet? The variable of straight channel marking was included to test the generality of the difference.

3. Straight Channel Marking by Intended Track. The two 800-foot channels were run twice with a change in intended track. The four resulting scenarios are Scenarios 5 through 8 in Figure 1. For the last two scenarios, instead of being instructed to stay at the center, the pilots were instructed to stay at the center of the right-hand half. A distribution of responses at a point other than the center was thus provided for an 800-foot channel where it is most potentially relevant to real-world situations.

1.3.1 The Straight Channel Marking by Spacing Comparison

The first four scenarios in Figure 1 were chosen to produce the interaction of straight channel marking (staggered versus gated) by spacing (5/8 nm versus 1-1/4 nm). The inclusion of this interaction here had two purposes. First, it made possible the comparison of the CAORF and USCG/EA simulations in their function of evaluating the effect of buoy-placement-related variables on piloting performance. It was decided that the replication of such an interaction was a more meaningful comparison of the CAORF and USCG/EA simulations than was the obvious replication of a single scenario. However, the constant conditions were such that two scenarios were identical to two run at CAORF. Therefore, the comparison of identical scenarios was possible as well. Second, the effects of these two variables and their interaction was worth replicating because of their importance to marking straight channels. Practically, it may be the case that either is acceptable under some circumstances and there is not always a justification for recommending a change in existing configurations. Theoretically, the findings of the CAORF experiment led to the conclusion that the piloting process is substantially different when buoys are staggered than when they are gated. Because of this, there is not only a main-effect difference between the conditions but also a difference in the

CHANNEL WIDTH EXPERIMENTAL DESIGN

1. STAGGERED 5/8 NM SPACING 500 FOOT WIDTH CENTER	2. GATED 5/8 NM SPACING 500 FOOT WIDTH CENTER
3. STAGGERED 1-1/4 NM SPACING 500 FOOT WIDTH CENTER	4. GATED 1-1/4 NM SPACING 500 FOOT WIDTH CENTER
5. STAGGERED 1-1/4 NM SPACING 800 FOOT WIDTH CENTER	6. GATED 1-1/4 NM SPACING 800 FOOT WIDTH CENTER
7. STAGGERED 1-1/4 NM SPACING 800 FOOT WIDTH RIGHT	8. GATED 1-1/4 NM SPACING 800 FOOT WIDTH RIGHT

STRAIGHT CHANNEL MARKINGS BY SPACING

STRAIGHT CHANNEL MARKINGS BY CHANNEL WIDTH

STRAIGHT CHANNEL MARKINGS BY INSTRUCTION

Figure 1. Channel Width Experimental Design

way in which they interact with other variables. As an example, piloting with gated buoys proved resistant to spacing differences in the CAORF experiment while piloting with staggered buoys did not. This relationship was discussed in Section 3 of the CAORF report (reference 1).

1.3.2 Straight Channel Marking by Channel Width Comparison

This two-way interaction was of straight channel marking (staggered versus gated buoys) with channel width (500 versus 800 feet). These conditions are listed as Scenarios 3 to 6 in Figure 1.

The CAORF experiment was run with a channel width of 500 feet. For this experiment it was necessary to choose a second value. Any value substantially smaller than 500 feet is impractical for the large merchant vessels that are seen as the principal beneficiaries of this research program. Therefore, the chosen value had to be substantially larger than 500 feet. According to the analysis of 32 ports, while the mean width of the distribution of channels deep enough for a tanker is near 500 feet, 48 percent are over 600 feet. The chosen value of 800 feet is substantially larger than 500 feet but still within the range of real-world possibilities. The Channel Width Presimulation Report predicted poorer performance with the greater channel width. It was the principal purpose of this experiment to quantify this deterioration.

Additional scenarios were included to allow the inspection of the straight channel marking by channel width interaction. This variety of conditions was meant to test the generality, taken from the CAORF experiment, that the reliable techniques afforded by gated buoys resist deterioration when conditions change. In the Channel Width Presimulation Report it was predicted that gated conditions would show less deterioration with channel width than would staggered conditions. The survey of 32 ports supports this prediction: wide channels are more frequently marked with gates.

For this comparison spacing was held constant at 1-1/4 nm spacing. It was at this spacing that the maximum difference was found between staggered and gated conditions. Here, when spacing was not of central interest, it was desirable that the other variables included show their effects. There was a more practical reason for choosing the longer spacing in the nature of the wider channel: if longer spacing leads to less precise performance, the wider channel has the room to accommodate it. The analysis of 32 U.S. ports found no systematic relationship between spacing and channel width, supporting the assumption that wide channels are not a problem that requires extra buoys.

1.3.3 Straight Channel Marking by Intended Track Comparison

The straight channel marking (staggered versus gated buoys) by intended track (center or right of channel) comparison was comprised of Scenarios 5 to 8 in Figure 1. The principal interest there was on the new variable of intended track. Until this experiment, pilots in the AN-VISUAL experiments were instructed to stay as close to the center as practical except when necessary to leave it to maneuver. This dictation of strategy was meant to minimize the crosstrack standard deviation, or that component of the crosstrack standard deviation, that was due to differences in strategy rather than to differences in perceptual effects. This meant that every distribution of responses was taken at or near the center of the channel. The

intended track was changed as one variable in this experiment: the pilot was asked to stay at the center of the right-hand half of the channel. Thus, a distribution of responses at another point in the channel was obtained. It had been decided that the 800-foot channel was the proper context for this change. In a wider channel in the real world, pilots are more likely to change their strategy and to stay to the right of the center. They would not necessarily stay on the center of the right-hand half, but the intent was to narrow the crosstrack standard deviation by restricting strategy as was done at the centerline.

The straight channel marking difference was maintained here to again test the generality of the supposed difference in technique with staggered and gated buoys. The Channel Width Presimulation Report made two alternative predictions for this interaction:

1. If the pilots used buoys on both sides to judge their crosstrack position with the right-hand track as they did for the centerline track, gates should have supported better performance on the right as they did at the center.

2. To the extent that pilots depended on the right-hand buoys, there should have been no difference between the staggered and gated conditions.

1.4 CONDITIONS CONSTANT TO ALL SCENARIOS

The differences in performance observed as a function of the experimental conditions described above must be interpreted in the context of the constant conditions. It is possible that changes in these background conditions might have caused changes in the relationships observed among the experimental conditions.

1. The visual conditions. All the scenarios were run under daytime conditions to take advantage of the new capability of the USCG/EA simulation to present day buoys that increase in height and width with decreasing distance. On the screen the pilots saw 17-foot unlighted buoys (black on the left, red on the right), and a horizontal demarcation between the sky (blue) and the sea (gray). This demarcation appears at the detection range of 1-1/2 nm. This is the longer of the two ranges used in the CAORF experiment. (The shorter, 3/4 nm, range resulted in unexpected performance effects that are assumed to be limited in their generality.)

2. The turn conditions. All turns in this experiment were 35-degree noncutoff turns with three buoys. In the CAORF experiment, the 35-degree noncutoff turns were the most difficult with the three buoys providing an impressive steadying of performance in the pullout. Such a turn was chosen to be sufficiently difficult to represent the perturbation of a wide range of turns but to have sufficient turnmarking to provide a pullout that would not contaminate straight channel performance beyond. The locations of the turn buoys are illustrated in Figure 2.

3. The ship. The ship was a 30,000 dwt tanker, 595 feet long and 84 feet wide with a 34-foot draft and a 45-foot height of eye. It had a split house configuration with a midships bridge 200 feet back from the bow. It was trimmed to present a relatively low bow image on the screen. Shallow water effects and a slow speed made it relatively difficult to handle for its size. This relative small tanker had room to maneuver in the narrow channel in this experiment where the size or maneuverability of the ship was not of central interest.

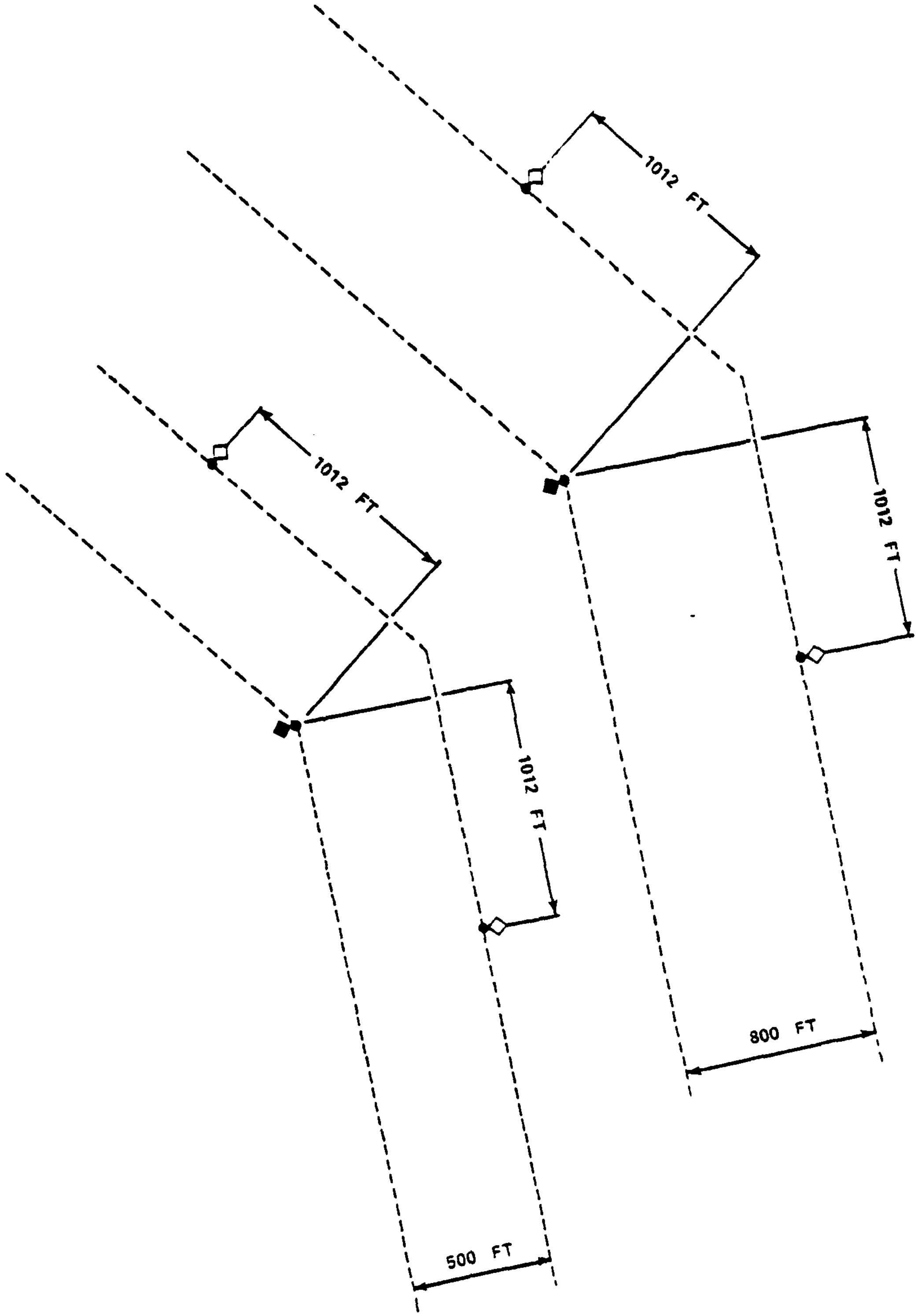

Figure 2. Location of Turn Buoys

4. The bridge conditions. The pilot had available the following:

- A helmsman to receive his orders.
- A gyrocompass.
- An engine order telegraph (with the occasionally taken opportunity to increase his speed in the turn).
- Charts of the channel with the course and buoy locations.
- A diagram of the current conditions.
- No radar (this was an experiment in visual piloting).

5. The performance requirements. The performance requirements are summarized in Figure 3. The ship was initialized 2.3 nm below the turn and 100 feet to the right of the centerline. At that point there was a following current which decreased from 1-1/4 knots and a following wind of 30 knots and gusting. The pilot was instructed to take the ship to the designated trackline. He could leave that trackline when ready to negotiate the turn by his own strategy. He was asked to return to the designated track in the next leg as soon as possible. As he entered the new leg, the wind and current were broad on his port quarter. Given the current velocity of 3/4 knots and his speed through the water of 6-1/2 knots, he needed a drift angle of 3 degrees to maintain the course of the channel. As he attempted to return to the designated trackline, the current velocity, and the necessary drift angle, decreased, reaching zero at the end of the scenario. The wind remained the same in direction and average intensity throughout the run. The instructions to the pilot and the postsimulation questionnaire appear as Appendices B and C. The wind and current effects are described more specifically in Appendix D.

The scenario was truncated from what it had been in the CAORF experiment. The traffic ship included there in Leg 1 was omitted here for two reasons. Experimentally, at CAORF it had not proved to be a difficult task with a following current. Practically, the USCG/EA simulator cannot presently simulate traffic ships in the day scene. The point at which the new scenario was initialized was 3 minutes or 2380 feet before the average point at which ownship passed the traffic ship at CAORF.

1.5 DATA COLLECTION AND PERFORMANCE MEASURES

The principal data collected described the ship's status at short intervals as it transited the channel. When the ship crossed the data lines diagrammed in Figure 4 or when the pilot made the responses described below, the computer recorded the following measures:

- Time of event.
- Ship's center of gravity position.
- Ship's bridge position.
- Ship's velocity relative to the ground.
- Ship's true heading.
- Rate of turn.
- Rudder angle.

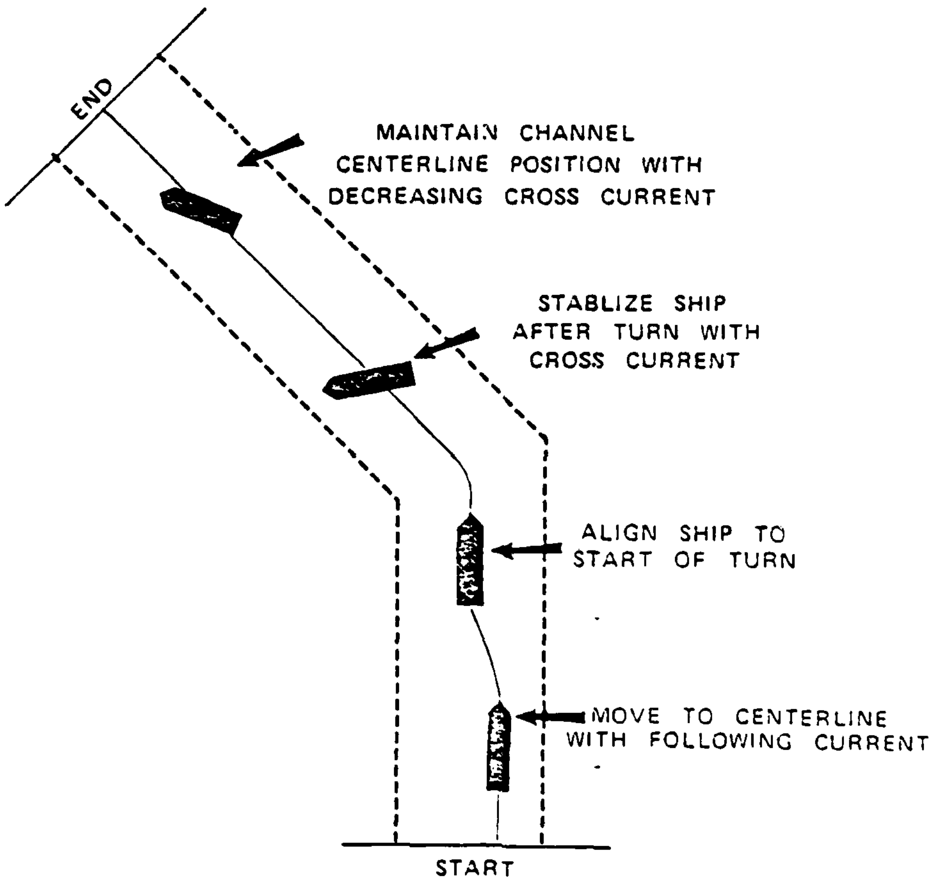

Figure 3. Performance Requirements in the Channel Width Scenarios

DATA COLLECTION

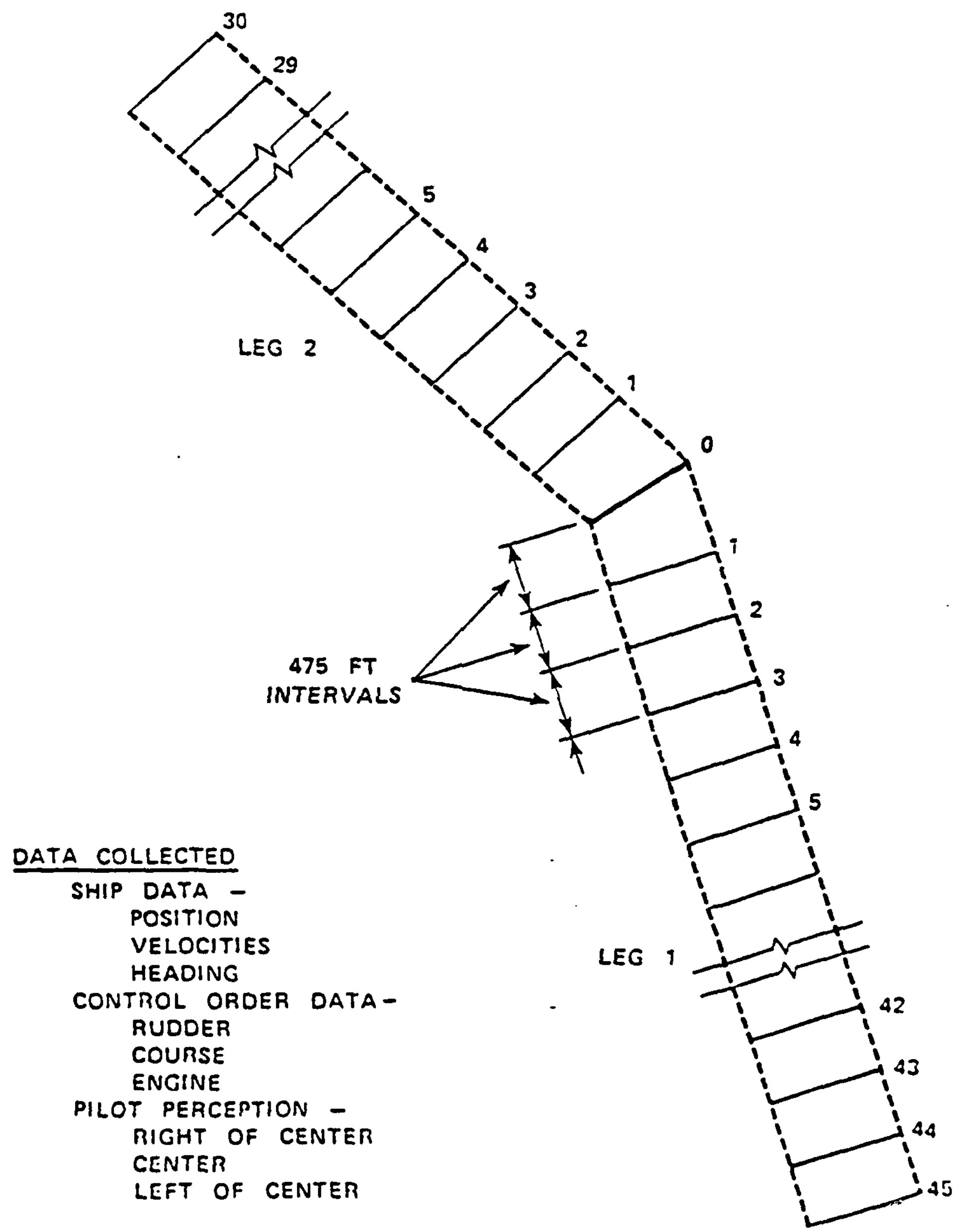

Figure 4. Data Collection Lines

- Course made good.
- RPM of propeller.

Additional data recorded include the pilot's helm orders and judgments of his crosstrack position. When the pilot gave an order to the helmsman, this order was entered by an observer at a computer terminal. The computer recorded this entry along with the data on ship's status listed above. A response panel was designed for this experiment to permit the pilot to report his perception of his relationships to the centerline. The panel had three buttons that were lit at intervals as a request that the pilot judge his position to be on the designated trackline or to its left or right. Again, measures of the ship's status were recorded with these responses. The helm orders and perceptual reponses are not discussed in this report. The data collection process and responses are discussed in greater detail in the presimulation report.

The performance measures are compilations of data on the position of the ship's center of gravity. The basic measure of the ship's crosstrack position were treated as illustrated in Figure 5. The mean and standard deviation was calculated at each data line for the set of conditions to be described. The first set of axes shows the means; the second, the standard deviation. On the last axes is a "combined plot" which shows the band formed by the mean and two standard deviations to either side of it against the boundaries of the channel. The band encloses 95 percent of expected transits under the experimental conditions sampled. The placement (mean) and width (standard deviation) of this band within the boundaries of the channel are together a quantitative description of the set of transits under these conditions, and, therefore, of the performance of the buoy arrangements.

The trackkeeping portions of the scenario are the easiest to interpret. It is assumed that, because of instructions, the pilots are attempting to keep the ship on the designated track. The distance of the mean off the centerline and the spread measured by the standard deviations are indications of the performance of the buoy arrangement for the conditions sampled. Therefore, the best buoy arrangement is one that puts the mean of the distribution on the trackline and minimizes the standard deviation. Performance in the maneuvering portions is more difficult to interpret. The distribution of crosstrack portions contains the variations in pilots' strategies as well as the performance of the buoys in guiding them in those strategies. An adequate buoy arrangement should keep the combined plot well inside the channel.

There is an assumption in this discussion that the precision in piloting performance that a buoy arrangement affords is related to the safety of that channel: a safely-marked channel is one that results in a distribution of transits that is well within the channel boundary for both trackkeeping and maneuvering. It should be reemphasized that these measures are derived from an experiment and not a real-world situation. They are measures of performance under the experimental conditions (the experimental design and the simulation) used. For application to real-world channels, they must be considered relative measures of the performance of buoy arrangements or channel conditions. The interpretation of these performance measures as probability of grounding, for example, would be incorrect pending validation of such interpretation in the real world.

OUTPUT FORMAT

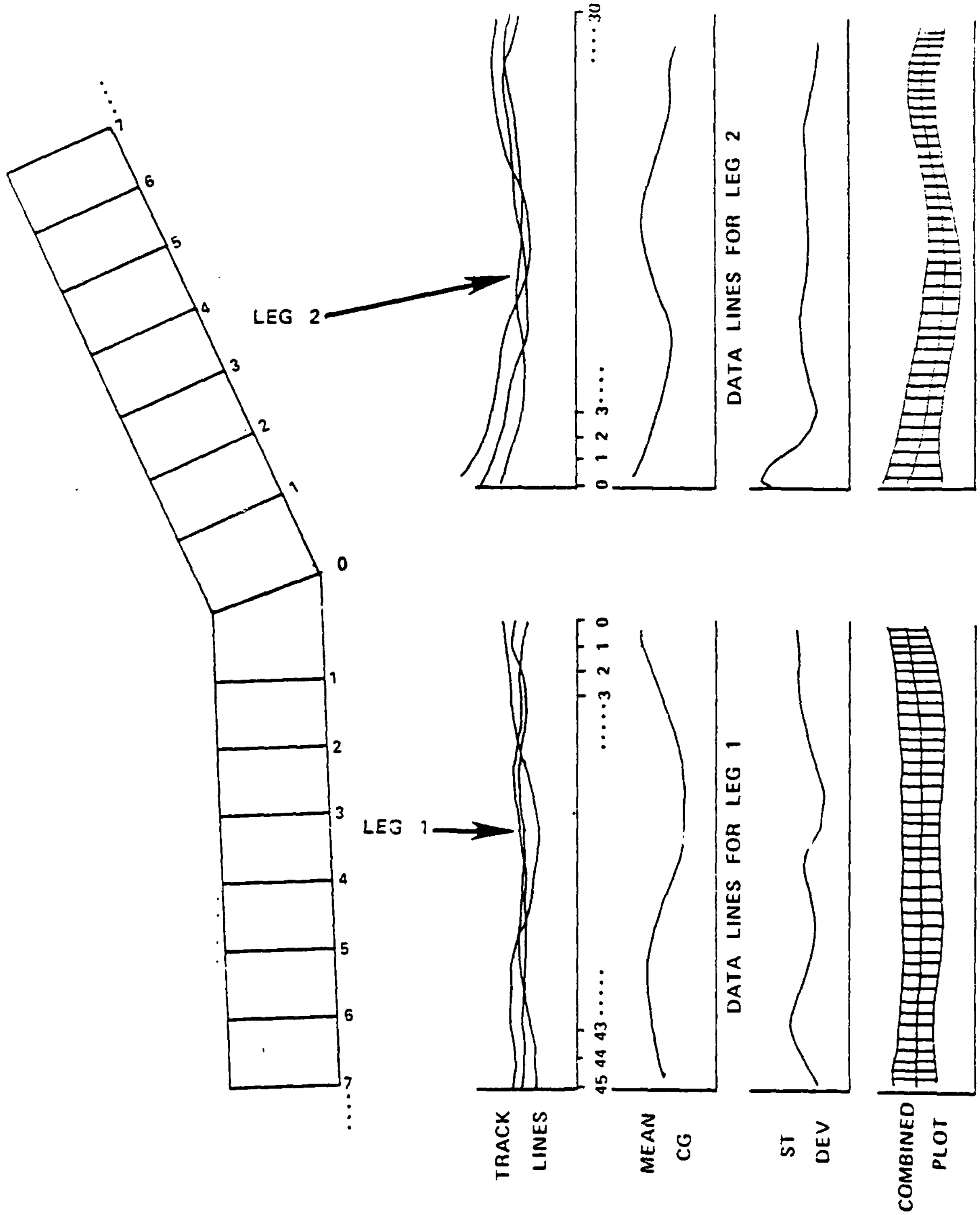

Figure 5. Data Collection Lines and Output Format

Section 2

PERFORMANCE AS A FUNCTION OF THE STRAIGHT CHANNEL MARKING BY SPACING COMPARISON

As a general overview of the results in this section, the effect of perturbation (Leg 1 versus Leg 2) is greater than the effects of the experimental conditions within either leg. Performance under three of the four combinations of straight channel marking and spacing is roughly equivalent. Performance under the fourth, staggered buoys spaced at 1-1/4 nm, is significantly poorer. It is inferred that the pilots were using a different strategy in that condition than in the others.

2.1 LEG 1 VERSUS LEG 2

Representative values for performance are summarized in Table 2. The figures selected were the maximum crosstrack standard deviation before Data Line 11 in Leg 1 and after Data Line 11 in Leg 2 and the crosstrack mean at that point. These values were chosen on the assumption that they represent the maximum difficulty in the straight leg while values closer to the turn represent the turn conditions. The most obvious effect is a difference between the two legs: performance is much more precise in Leg 1. In Leg 1, the overall mean was essentially on the 250-foot line that is the center of the channel and the overall standard deviation was approximately 40 feet. The perturbation of Leg 2 displaced the overall mean more than 50 feet to the right and doubled the standard deviation to 80 feet. The table identifies those Leg 1-Leg 2 differences that are significantly different. The means were compared with a t-test; the standard deviations were compared as variances with an F-test.[8] For both tests, an asterisk indicates a probability of less than 0.05 that the difference occurred by chance. The significant difference in standard deviation (variance) are also indicated in Figure 6 which illustrates the relationship among the standard deviations.

2.2 THE COMBINATIONS OF STRAIGHT CHANNEL MARKING AND SPACING

Differences among the four conditions within each leg were not as great as those between legs. The means in Table 2 were compared within each leg with a two-by-two analysis of variance[9] and there were no significant differences. Among the standard deviations, only the difference between the two spacings with staggered buoy in Leg 1 yielded significance. These relatively small differences among the conditions are consistent with their original selection: the configurations and spacing involved are representative of existing conditions in U.S. ports.

Performance over the length of the scenario under the four conditions supports the inference that the pilots used a different strategy with the staggered, 1-1/4 nm location than they did with the other three combinations. Their strategy for this most difficult condition is revealed in Figure 7. The mean of the crosstrack position of the transits, which is plotted at the top of the page, shows a tendency to approach

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[8] Quinn McNemar. Psychological Statistics. Fourth Edition, New York, John Wiley and Sons, Inc., 1969.

[9] J.L. Myers. Fundamentals of Experimental Design. Third Edition, Boston, Allyn and Bacon, 1979.

TABLE 2. THE EFFECTS OF STRAIGHT CHANNEL MARKING AND SPACING IN LEGS 1 AND 2
(ENTRIES ARE IN FEET)

Conditions		Leg 1	Distance Offtrack	Leg 2	Distance Offtrack	Difference Between Legs	Significance of Difference
Staggered 5/8 nm	Mean	234	16R	187	63R	47	*
	Maximum standard deviation	29		69		40	*
Staggered 1-1/4 nm	Mean	255	5L	218	32R	37	
	Maximum standard deviation	65		103		38	
Gated 5/8 nm	Mean	256	6L	198	52R	58	*
	Maximum standard deviation	40		66		26	
Gated 1-1/4 nm	Mean	246	4R	182	68R	64	*
	Maximum standard deviation	40		85		45	*

*Differences with $p \leq 0.05$

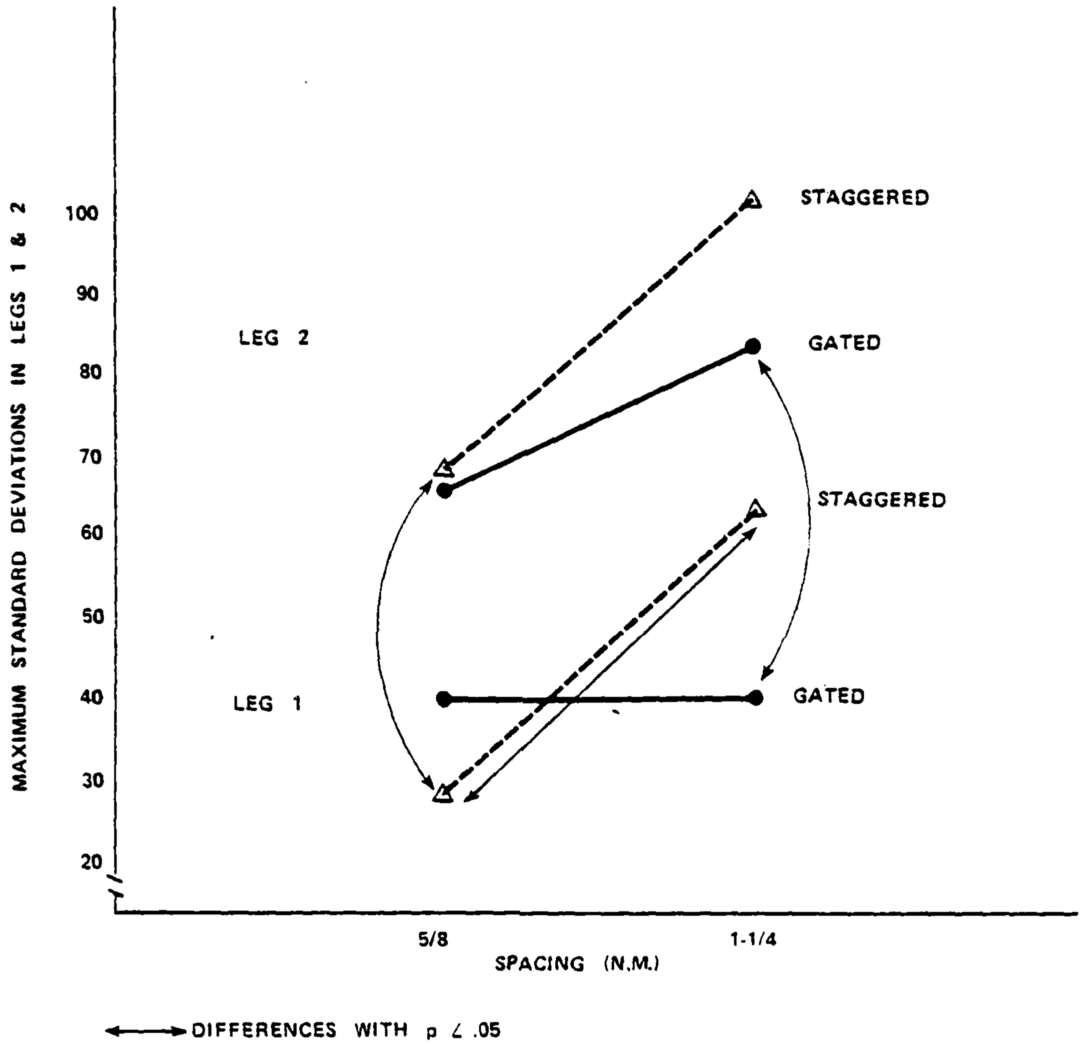

Figure 6. The Straight Channel Marking by Spacing Interaction

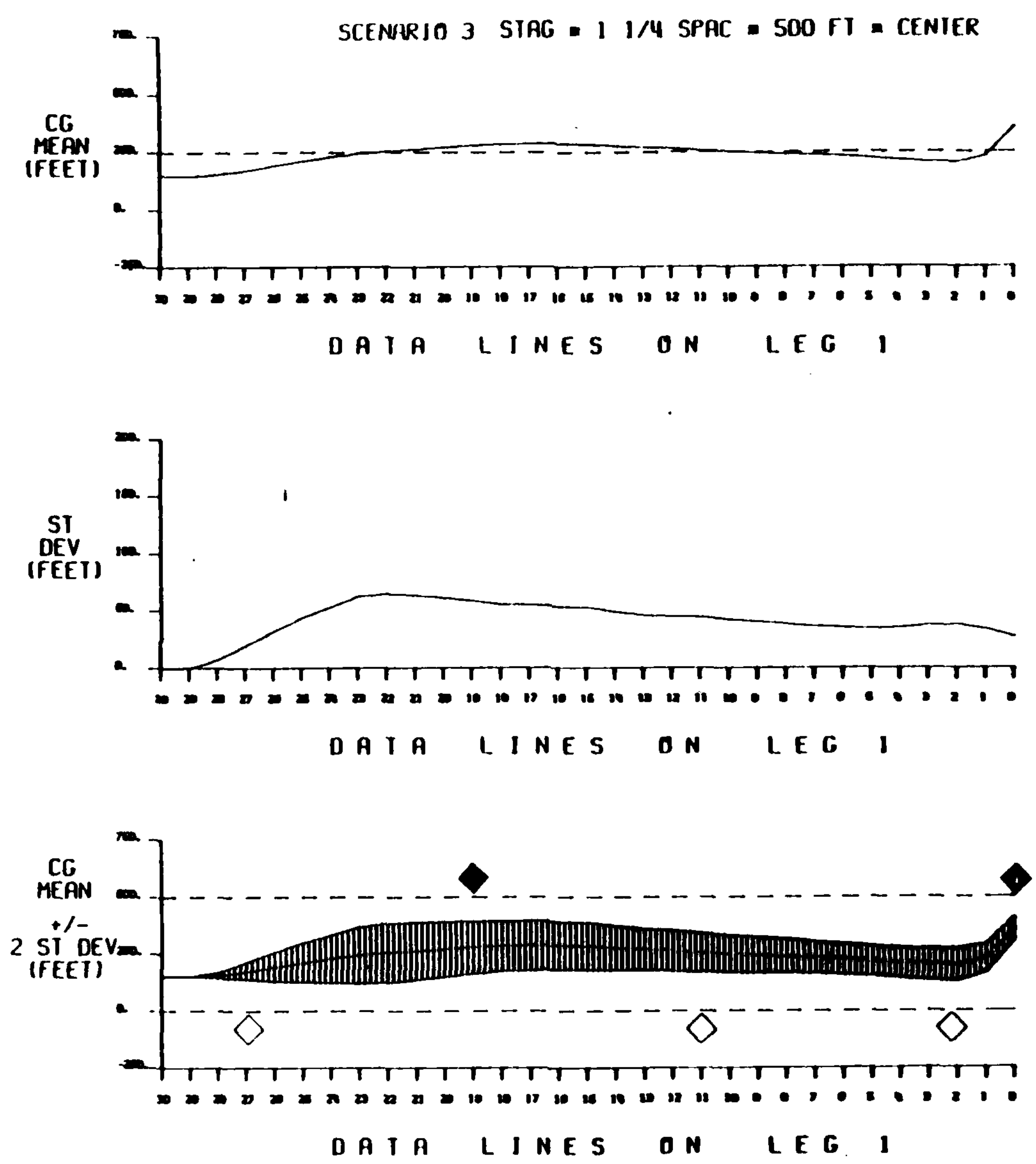

Figure 7. Performance in the Staggered, 1-1/4 NM Spacing Condition 500-Foot Channel in Leg 1

each buoy as it passes to the side. Pilots call this "zigzagging" or "buoy-hopping" when they describe doing it in the real world. Performance for the other three conditions does not show this pattern for the plot of the mean. For them the mean moves more gradually to the centerline and does not overshoot it. Leg 2 shows a similar difference between this condition and the other three. (Plots for all four conditions in both legs are available in the earlier published trackplots for this experiment.[10] This difference in strategy has consequences for both the means and the standard deviations. Table 3 summarizes a contrast between the staggered, 1-1/4 nm spacing conditions and the other three. In Leg 1 both the mean and the standard deviation are different at the 0.05 level. In Leg 2, where performance deteriorates for all conditions, differences for both measures approach but do not reach significance. These numbers must be interpreted in terms of the pilots' strategy. The means selected to represent that condition in Table 4 were "better" than the others in that they were closer to the centerline (250 feet). Inspection of the top plot in Figure 7 shows that the mean approaches the centerline (earlier than in the other conditions) on its way to the far side. The "better" means were the result of the strategy and did not result from the pilots' greater certainty as to their position under those conditions. On the contrary, it was associated with a greater standard deviation, a wider band, and less precision.

A possible reason for the increase in standard deviation in the middle of Leg 1, especially in the 1-1/4 nm spacing conditions, is discussed in Section 3.

Plots comparing performance over the length of the scenario for pairs of conditions are available as Appendix D. They include comparisons of the two spacing conditions (5/8 versus 1-1/4 nm) and of the two straight channel marking conditions (staggered versus gated). The plots compare both the means and the standard deviations. A symbol marks each data line for which the statistics are different at the 0.05 level. Other major comparisons in this experiment are included in that appendix.

TABLE 3. THE STAGGERED, 1-1/4 SPACING CONDITION
COMPARED TO THE OTHERS (THE ENTIRES ARE IN FEET)

		Leg 1	Leg 2
Staggered, 1-1/4 nm	Mean	255	218
	Maximum standard deviation	65	103
Others	Mean	246	189
	Maximum standard deviation	36	73

Differences with
*p≤0.05
+p≤0.10

[10]Eclectech Associates. Preliminary Performance Data AN Visual Channel Width Track Plots. U.S. Coast Guard, Washington, D.C., October 1980, pp. 1.1-11 to 1.1-14 and 2.1-11 to 2.1-14.

TABLE 4. THE EFFECTS OF STRAIGHT CHANNEL MARKING IN THE PULLOUT (ENTRIES ARE IN FEET)

Conditions		
Staggered, 5/8 nm	Mean	150
	Standard deviation	51
Gated, 5/8 nm	Mean	186
	Standard deviation	66
Staggered, 1-1/4 nm	Mean	150
	Standard deviation	79
Gated, 1-1/4 nm	Mean	174
	Standard deviation	29

⟷ Differences with $p \leq 0.05$

2.3 THE PULLOUT FROM THE TURN

The results can be analyzed for differences in performance in the pullout from the turn as a function of conditions. All the turns were the same in angle, radius, and number of turnmarking, as described in Section 1.3. Therefore, differences in pullout performance are attributable only to straight channel marking and spacing, to what the pilot saw ahead. The measures used to describe pullout performance in the four different conditions were the crosstrack mean and standard deviation at Data Line 11 in Leg 2 (5225 feet beyond the apex of the turn). These measures are summarized in Table 4. Those differences that are significant at the 0.05 level are indicated in that table. The interaction among the standard deviations is graphed in Figure 8. The staggered conditions behave as might be expected from the straight channel effects: the short spacing is better than the long. The maximum standard deviation in the pullout is 51 feet for the 5/8 nm condition and 79 feet for the 1-1/4 nm condition (this difference is not significant).

The pullout was good in both gated conditions. However, the relationship between them seemed to contradict both the straight leg results and general expectancies. For the 5/8 nm condition the mean was better, closer to the centerline, than it was in the 1-1/4 nm condition; but not significantly so. However, the standard deviation for the 5/8 nm condition was worse at 66 feet, significantly worse than the 29 feet for the 1-1/4 nm condition. Performance in Leg 2 for these two conditions is illustrated by the combined plots in Figures 9A and 9B which shows the greater precision with the longer spacing.

Paradoxically, the condition with the best information did not seem to have the best performance. Each data line represents 475 feet of alongtrack distance; the buoys, spaced at 5/8 and 1-1/4 nm, are indicated on the plots; detection range is 1-1/2 nm throughout. These distances mean that in the pullout in the 5/8 nm condition the pilots saw two gates which outlined the slopes or edges of the channel. Is it possible that slopes were less effective a guide than one gate? Or was some other explanation for the larger standard deviation in the 5/8 nm spacing condition possible?

The possibility of too much buoy information has been suggested; that too many buoys lead to "over-control." This means the pilot tries too hard to achieve a

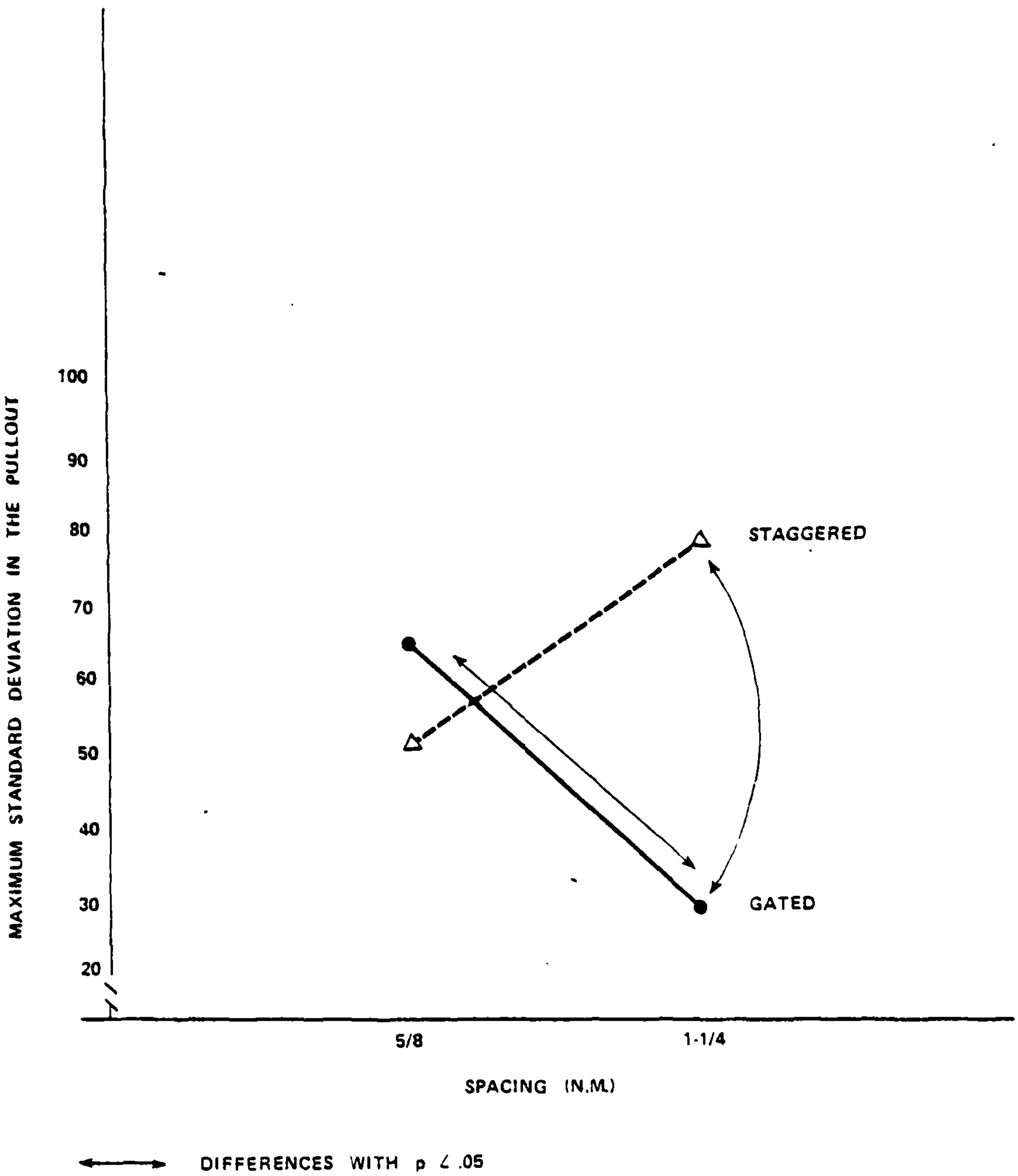

Figure 8. The Straight Channel Marking by Spacing Interaction in the Pullout

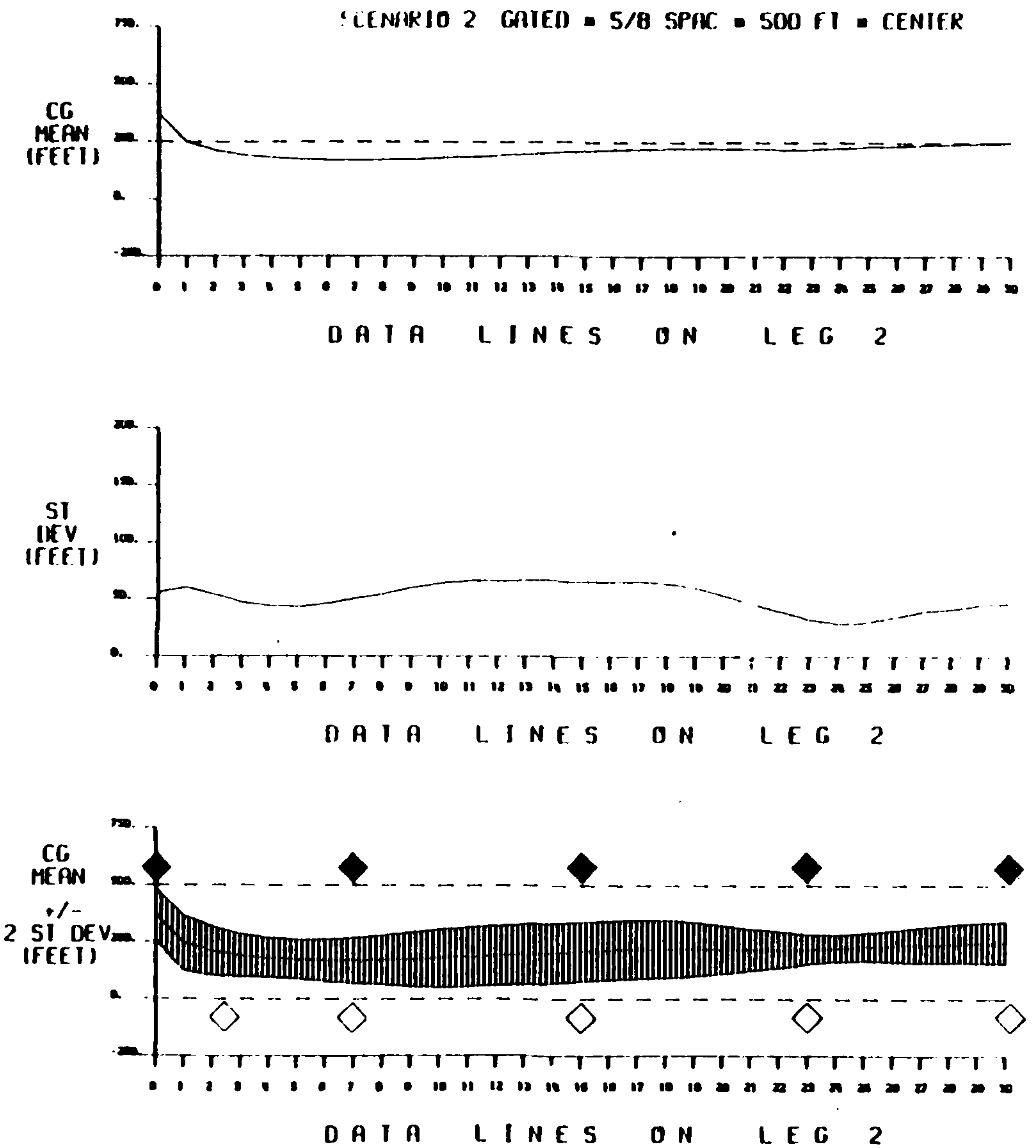

Figure 9A. Performance in Leg 2 for the Gated 5/8 NM Condition

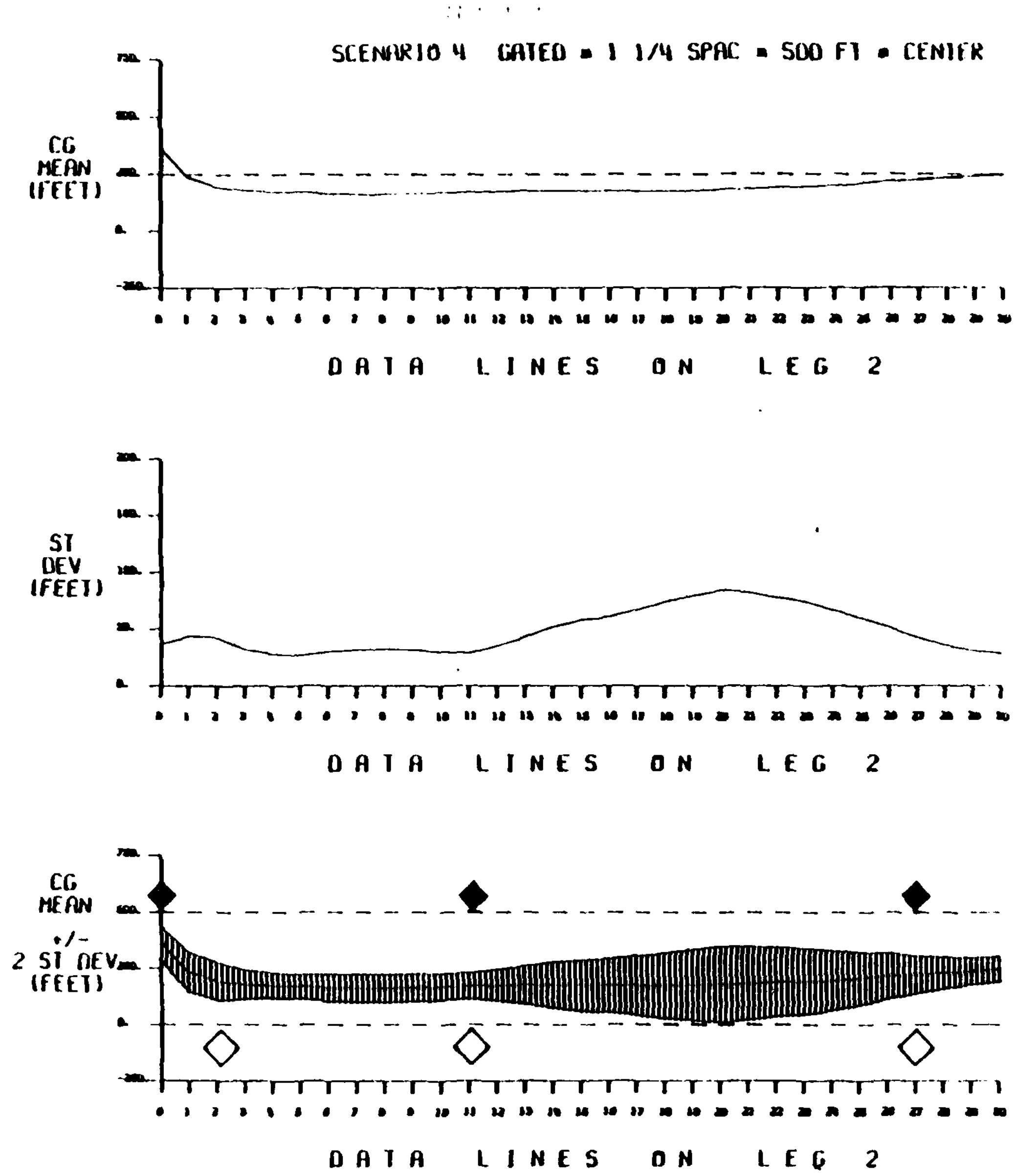

Figure 9B. Performance in Leg 2 for the Gated, 1-1/4 NM Condition with 500-Foot Width

precise track, giving a great many helm orders with resulting frequent changes in the heading of the ship. Because of the time lags between the giving of an order, the ship's response, the pilot's perception that he has overshot his intended track, his giving of a new order, and the ship's new response; such over-control would be expected to result in a greater standard deviation of crosstrack positions, even while achieving a better mean. The helm orders given for the two gated conditions in Leg 2 are illustrated in Figures 10A and 10B. There do, indeed, seem to be more rudder orders in the pullout for the 5/8 nm conditions. Further analysis of the data would be necessary to determine whether the larger number of helm orders constitutes "over-control." It is possible that they represent more, but smaller, heading changes and no more perturbation of the ship. Such a strategy would not be an undesirable result of high information.

An alternative explanation for the larger standard deviation in the high information condition is that the observed performance represents the pooling of several tracks or strategies. The turn in the gated 5/8 nm condition presented the pilot with a situation in which he had very high information and no restrictions on his strategy (unlike the straight channel segments in which he was instructed to stay on the centerline). The pilots' strategies under such conditions are illustrated in Figure 11A. The tracks are individual runs through the turn for the specific scenario. The plot shows the outline of the 35-degree run in a 500-foot channel with the turn buoys indicated. The plots start and end at alongtrack distances equivalent to Data Line 5 in the plots for Legs 1 and 2. They split into two different strategies: most went to the inside of the turn to allow for the current, while several made an ambitious attempt to stay at the centerline all the way through the turn. For comparison, the tracks through the turn are also presented in the 1-1/4 nm condition as Figure 11B. There, the pilots adopted a conservative strategy intermediate between the two. Apparently, the high information value of the 5/8 nm, gated condition gave the pilots the certainty to allow them to try a variety of strategies. Such a relationship between high information and high variability was also found in another study done for the U.S. Coast Guard. An analysis of approach to a deepwater port found that radar displays with high information value were associated with more varied strategies.[11]

The larger standard deviation in a high information condition should not be interpreted as uncertainty of position relative to the low information condition. (It should be emphasized that the standard deviations are not absolutely large.) Of the other possible interpretations, the pooling of alternative strategies seems the most plausible. The larger number of helm orders is potentially compatible with the alternative strategies; the split in the distribution of tracks is not compatible with "over-control." Apparently, the pilots were so certain of their position that, when they had the opportunity, they chose more difficult tracks for themselves and gave more helm orders to achieve those tracks. In those segments of the channel where the track was fixed, they were well able to maintain the track without extra effort and showed the precision of performance to be expected with high buoy information.

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[11] R.C. Cook, R.B. Cooper and K.L. Marino. A Simulator Study of Deepwater Ports Shiphandling and Navigation Problems in Poor Visibility. U.S. Coast Guard, Washington, D.C., October 1980.

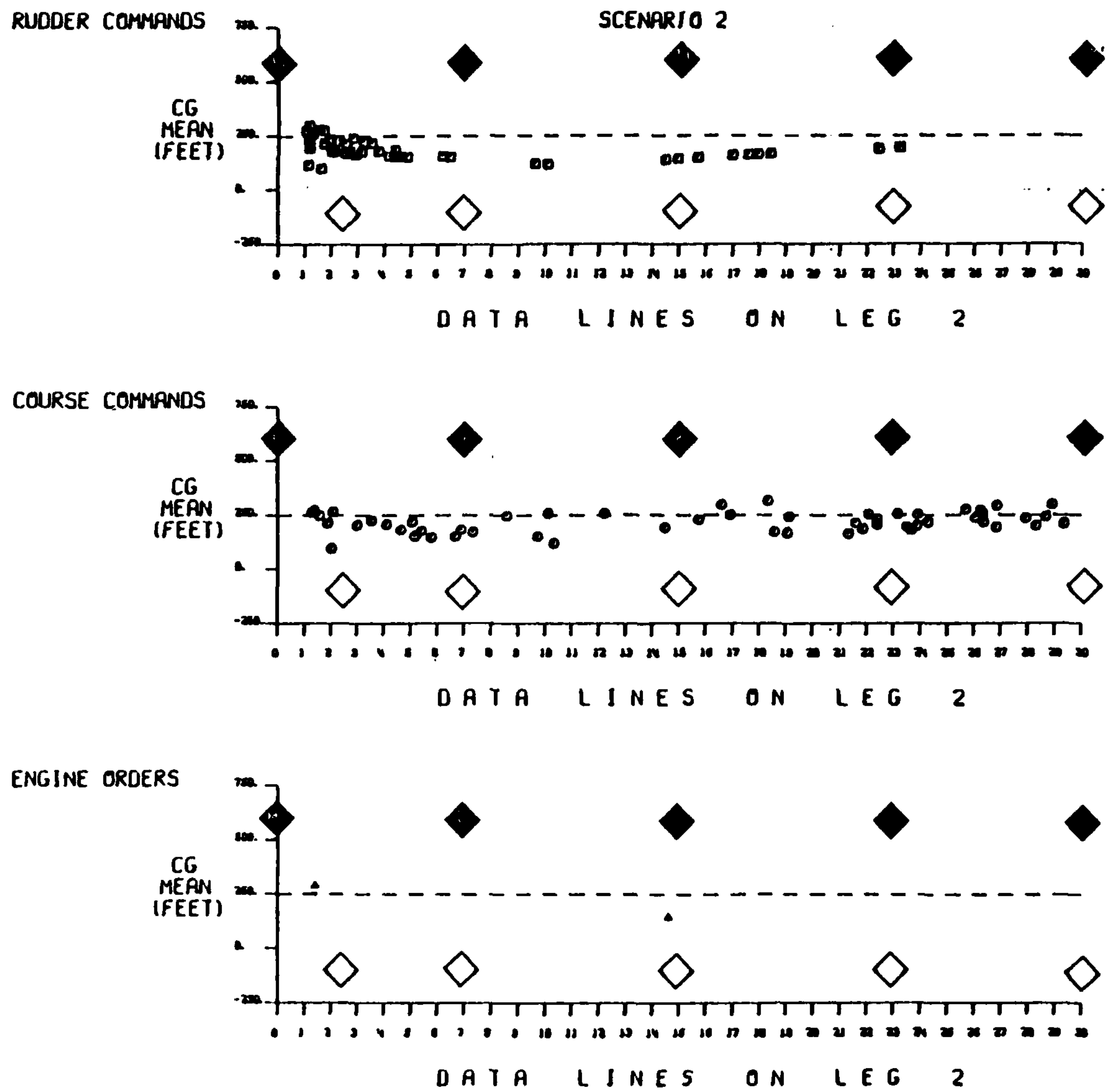


Figure 10A. Helm Orders in Leg 2 for the Gated, 5/8 NM Condition

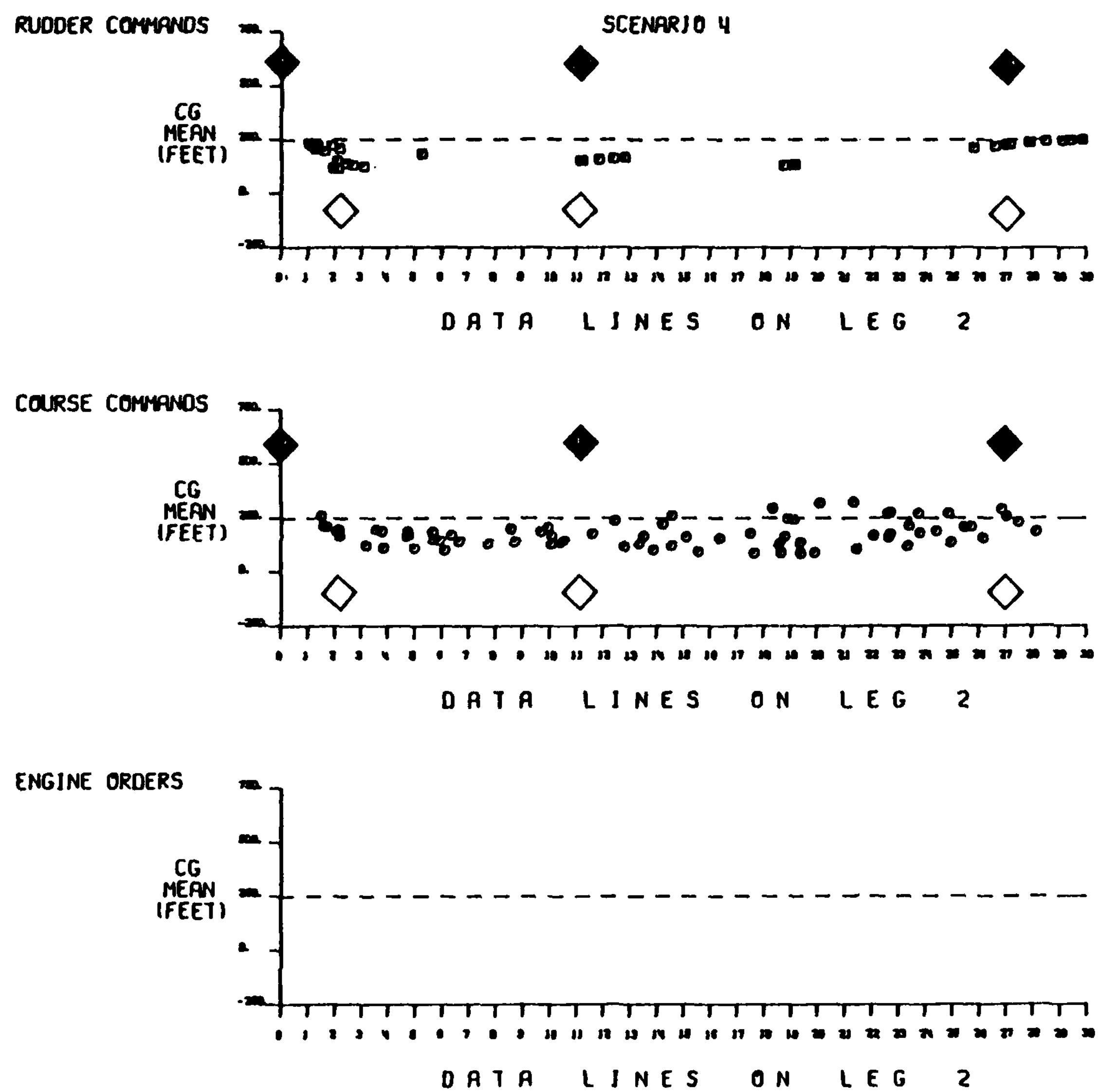


Figure 10B. Helm Orders in Leg 2 for the Gated, 1-1/4 NM Condition

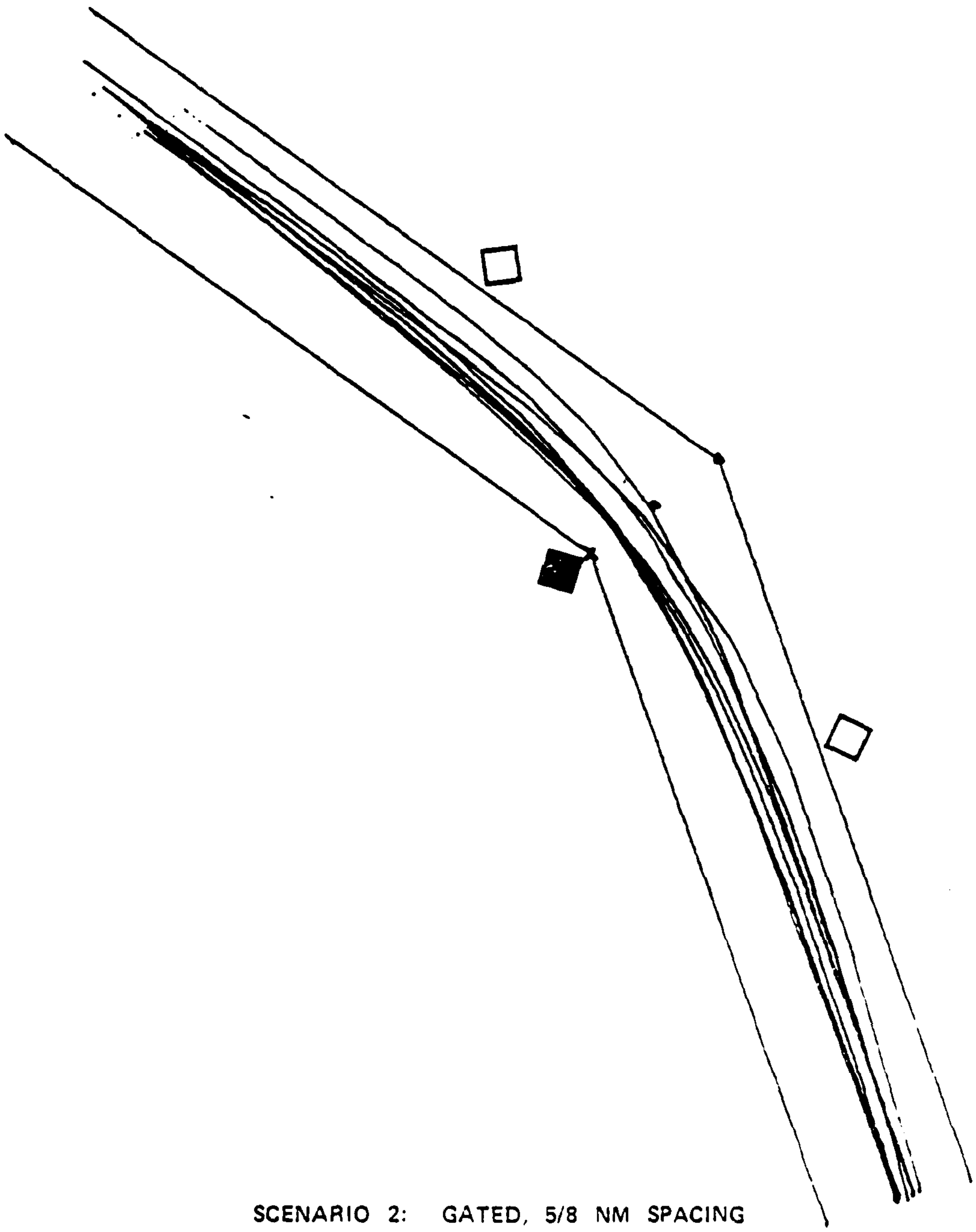
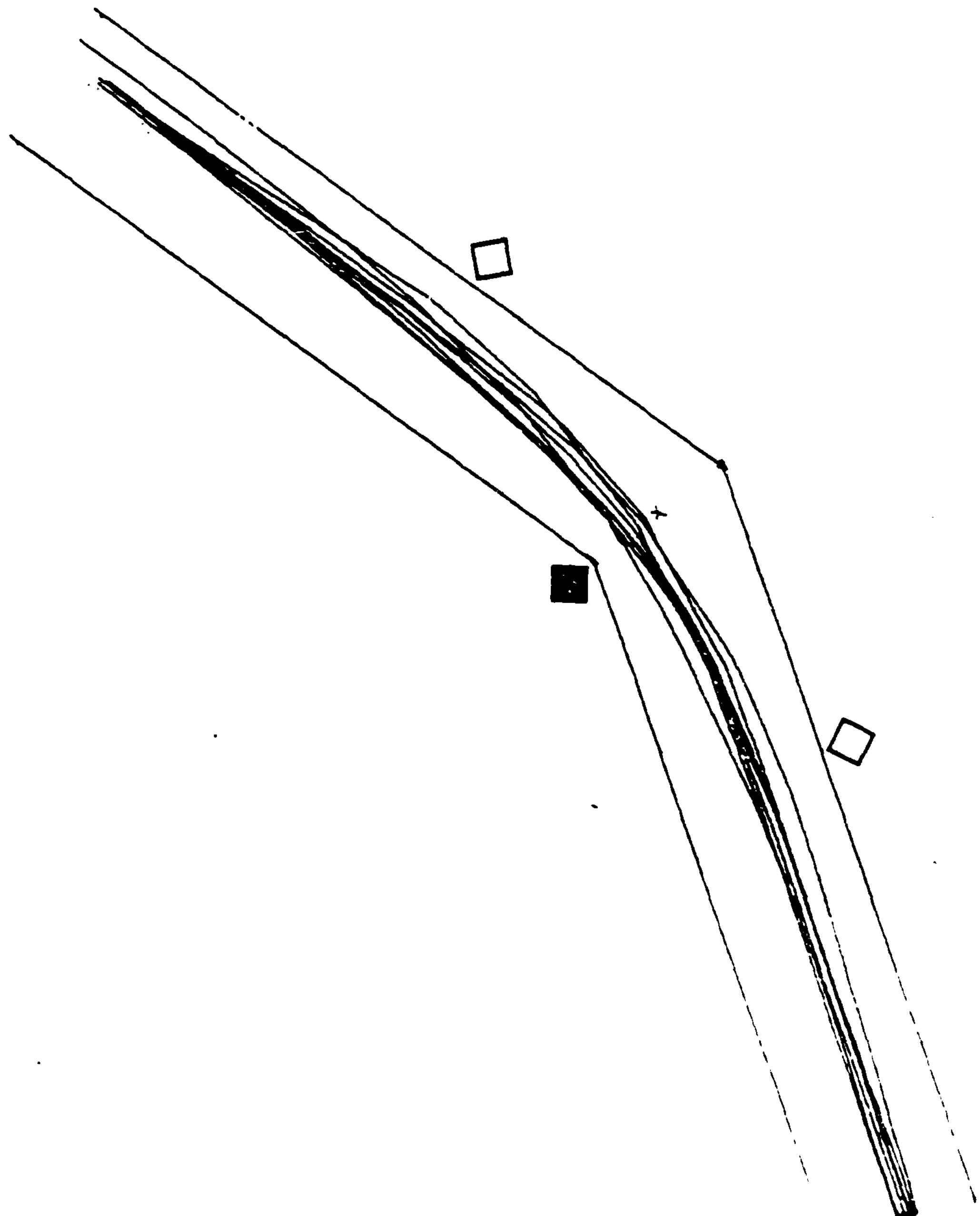


Figure 11A. Pilots' Strategies in Leg 2 for the Gated, 5/8 NM Condition



SCENARIO 4: GATED, 1-1/4 NM SPACING

Figure 11B. Pilots' Strategies in Leg 2 for the Gated, 1-1/4 NM Condition

TABLE 5. THE EFFECTS OF CURRENT AND WIND (THE ENTRIES ARE IN FEET)

		Leg 1, Line 11	Leg 2, Line 11	Leg 2, Line 30
Stag, 5/8 nm	Mean	250	150	229
	Standard Deviation	22	51	29
Gated, 5/8 nm	Mean	252	186	251
	Standard deviation	31	66	46
Stag, 1-1/4 nm	Mean	255	150	253
	Standard deviation	44	79	45
Gated, 1-1/4 nm	Mean	243	174	250
	Standard deviation	26	29	28
Overall	Mean	250 ⟷	165 ⟷	245
	Standard deviation	31 ⟷	56 ⟷	31

⟷ Differences with $p \leq 0.05$

2.4 THE EFFECTS OF CURRENT AND WIND

The experiment was not designed with current as a between-scenarios variable. However, current did vary within the scenario: performance can be compared under different current conditions. The scenario described in Section 1.3 had a following current in Leg 1: the figures in the first column of Table 5 are means and standard deviation from Leg 1, Data Line 11; a point at which the pilots were trackkeeping, having recovered from the move to the centerline but not yet ready to navigate the turn. The figures in the second column are from Leg 2, Data Line 11; a point at which the pilots had recovered from the turn and were trying to achieve the centerline with a crosscurrent component of 1/4 knot and a compensating drift angle of 3 degrees. The last column represents trackkeeping on the centerline with the crosscurrent component reduced to zero: it should approximate Leg 1 performance. The overall performance shows the effect of crosscurrent: without it, means were essentially at the centerline (250 feet) and standard deivations were small (30 feet). With a 1/4-knot crosscurrent, the means were shifted an average of 85 feet in the down current direction and the standard deviations increased to an average of 56 feet, doubling in some conditions. The mitigation of this effect by channel marking is illustrated by the second column of figures: both gates and 5/8 nm spacing improved performance, gates more than short spacing. (The peculiarities of the gated, 5/8 nm condition that are discussed above introduced some ambiguity to the interpretation of the standard deviation.)

It is also possible to make a comparison on the effect of wind. In this first leg, represented by the values in the first column, there was a following wind of 30 knots with gusts. At the end of the second leg, represented by the values in the last column, the current had decreased to zero; but the wind was still 30 knots, now on the port quarter. There does not seem to be any effect on performance as a result of this crosswind: neither the overall mean nor the standard deviation differ significantly as a function of the change. Apparently, the helmsman and the pilot between them are able to compensate for the turning moment of the wind without affecting the ship's tracks.

2.5 SUMMARY

The observed performance in this comparison supports the generality that perturbation is the most important factor in channel design. When trackkeeping with no perturbation was all that was required, gates with long or short spacing and staggered buoys with short spacing all supported performance superior to staggered buoys with long spacing. When perturbation and/or maneuvering made the task more difficult, overall performance deteriorated. In mitigating this deterioration, gates and short spacing were both helpful. The gated-staggered distinction was relatively less important than the spacing distinction.

Changes in buoy conditions led to changes in strategy. Among the set of conditions discussed in this section, the staggered, 1-1/4 nm condition was associated with a different straight channel strategy than the others – zigzagging from buoy to buoy – and less precise performance. The gated, 5/8 nm condition was associated with a different pullout strategy – a more precise mean achieved by a greater number of heading changes. Changes in the straight channel buoy arrangements alone; any changes in channel characteristics, environmental conditions, ship characteristics, etc., led to changes in strategy.

Section 3

THE COMPARISON BETWEEN SIMULATIONS/SIMULATORS

This section begins by describing those aspects of the two simulations/simulators that might be expected to affect observed performance. The most central of these factors are ship hydrodynamics, environmental effects, and visual effects. There are minor differences in environmental effects and potentially moderate differences in visual data bases.

Performance observed with the two simulations is compared, using first the effects of two major variables (straight channel marking and spacing) on the maximum standard deviation in the straight channel. The relationships among conditions is similar with the two simulations but the absolute values differ with the USCG/EA simulation yielding larger standard deviations.

Observed performance is also compared using the effects of the piloting requirements over the course of the scenario. These effects are similar for much of the scenario. There are differences in Leg 2 with a crosscurrent, especially in those conditions with the least information. The discussion relates the differences in observed performance to differences in the simulation visual and environmental data bases described earlier.

It is concluded that the two simulations are similar in their usefulness for the exploration of the relationships between aids to navigation and piloting performance. Modifications that will reduce the differences between the two simulations and, potentially, in observed performance are suggested for subsequent experiments.

3.1 FACTORS TO CONSIDER

A project planned to use data from experiments done on two different simulators must demonstrate the similarity of performances on those two simulators. Ideally, the actual values measured should be the same on the two simulators. But repeatability of values is not always obtainable even on a single simulator. More practically, what is needed is a demonstration that experiments done on the same simulator lead to similar conclusions about the performance of aids to navigation. The size and variety of the CAORF experiment make it possible to select conditions and scenarios for replication in later experiments on the USCG/EA simulator. This replication allows comparison of results and conclusions on the two.

The present experiment was not "dedicated" to the comparison. Such an experiment would have required simulating identical conditions (as "identical" as possible), using the same pilots, and following the same experimental design. Any residual differences in performances could then have been attributed to simulator differences.

The word "simulation," rather than "simulator," is meant to emphasize the variety of components that might have contributed to differences in observed performance. These differences are summarized in Table 6 and discussed below.

1. Pilots. The pilots in the CAORF experiment were from the Sandy Hook and Delaware Bay Pilots Associations; those in the channel width experiment were federally-licensed pilots from the Northeast Pilots Association.

2. The experimental design. The experimental designs differed in two ways, which might affect the comparability of the data. First, the CAORF experiment included a greater variety of conditions. The data selected from that experiment

TABLE 6. DIFFERENCES BETWEEN CAORF AND USCG/EA SIMULATORS

	CAORF	USCG/EA
Pilots' association	Sandy Hook Delaware Bay	 Northeast
Experimental design	Pooled conditions between subject comparisons	Homogeneous conditions within-subject comparisons
Ship hydrodynamics	Same →	
Environmental effects		
Current	Identical →	
Wind	Minor differences →	
Visual effects		
Buoys	More distance cues	Fewer distance cues
View abeam	Not visible	Visible
Bow image	Larger	Smaller

for discussion in Section 3.2 below were pooled over a number of conditions that are not of interest here. This pooling increases the generality of the finding but it also means some ambiguity in identifying the source of the effect. The channel width experiment was a simpler design and the runs included in the comparison were homogeneous. This decreases both the generality and the ambiguity. Second, the CAORF experiment was a larger design and the subjects could not go through all conditions. Comparisons within the CAORF experiment are between measures taken on different subjects and containing an unknown amount of variability due to subjects. The channel width experiment was small enough for the subjects to go through all the conditions. Therefore, comparisons within that experiment are less ambiguously attributable to the experimental conditions rather than subject differences.

3. Ship hydrodynamics. The equations of motion and the hydrodynamic coefficients used in both the CAORF and the USCG/EA simulator were essentially equivalent. One notable difference in the simulations was the use of different integration intervals. The interval was 0.5 seconds at CAORF and 1.0 seconds for the USCG/EA simulation. This difference, however, did not significantly change the dynamic response of USCG/EA simulation. This was verified by comparing identical sea trial maneuvers conducted on each simulation.

Table 7 contains measures of turning performance obtained at CAORF and for the USCG/EA simulation. The tests were run for equal shallow water depths on the two simulators and for no wind and no current. The data represent distances in nautical miles for the measures indicated. The maneuver executed was a right turn through a 180-degree heading change using a constant rudder angle and constant rpm as indicated. The advance and transfer distances are at 90-degree heading change from the original heading, while the tactical diameter is at 180-degree change of heading from the original heading. These data verify identical dynamic response occurs on both simulators.

4. Environmental (current and wind) effects. Some of the wind and current parameters at CAORF were time varying functions. These functions were either trigonometric or of a random nature. (Note: The random functions were made repeatable for each scenario by utilizing identical random number seeds for the RN generators.)

TABLE 7. HYDRODYNAMIC RESPONSE CHARACTERISTICS FOR THE CAORF AND THE USCG/EA SIMULATIONS

RPM Revolution/Min	Rudder Angle Degrees	Advance (nm)		Transfer (nm)		Tactical Diameter (nm)	
		USCG/EA	CAORF	USCG/EA	CAORF	USCG/EA	CAORF
40	10^{o}R	0.70	0.70			1.17	1.20
	20^{o}R	0.47	0.47	0.40	0.40	0.79	0.82
	35^{o}R	0.32	0.31	0.39	0.38	0.64	0.64
60	10^{o}R	0.69	0.63	0.56	0.56	1.13	1.15
	20^{o}R	0.43	0.42	0.37	0.37	0.75	0.75
	35^{o}R	0.31	0.31	0.31	0.31	0.58	0.59

The current speed and direction were identical for the CAORF and USCG/EA simulations. The current speed was a trigonometric function that caused a maximum current speed at the start of the scenario but reduced to zero at 45 minutes, the approximate elapsed time at the end of the scenario. The current speed function is shown in Figure 12. Because the channel width scenario was initilized closer to the turn, the current speed function was initialized at $t_o = 10.48$ minutes for the channel width scenario.

The current direction was constant for both the CAORF and USCG/EA simulations. The current flowed towards 341 degrees true.

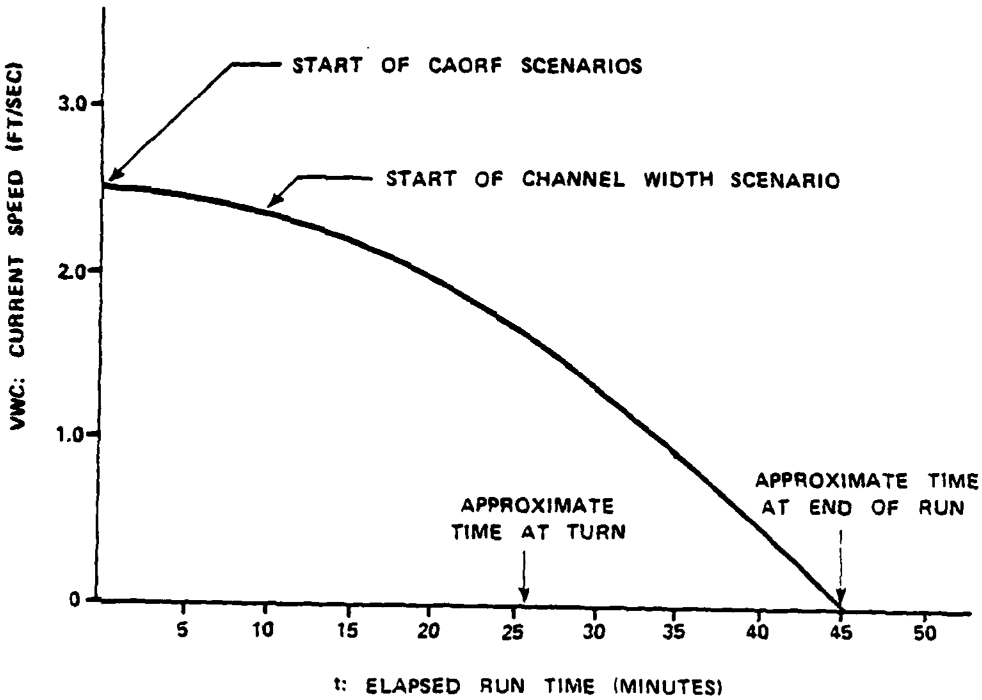
The wind speed was a random function for the CAORF simulation. This function was approximated by an algebraic and trigonometric function for the USCG/EA simulation. A comparison of these functions is shown in Figure 13. The wind magnitude is seen to increase steadily with time and vary sinusoidally with a 3-minute period. Although a perfect match was not obtained, it is believed that the differences which can be seen resulted in negligible differences in performance. (The reasons for this belief are discussed further in Section 3.3.)

The wind direction function was also a random function for the CAORF simulation. This function was approximated by a step function on the USCG/EA simulator. A comparison of these functions is shown in Figure 14. Here, it is seen that for portions of Leg 2 (before the turn) and portions of Leg 2 (following the turn), the wind directions on the USCG/EA simulation was 7 to 10 degrees further south than at CAORF. This difference may have resulted in a slight increase in the wind-induced turning moment, especially Leg 2. This increase, however, was not more thar 15 percent in magnitude. Nevertheless, the difference in direction noted may have potentially contributed to an increased track variation in the channel width scenarios. Because the wind "perturbation" was greater there, Leg 2 would be particularly susceptible to increased track variation.

5. Visual effects. The images of the buoys differed in the depth or distance cues offered. The CAORF buoys offered more depth or distance cues by fading the color or intensity of the buoys into the background fog color with distance, rendering a perspective view of the buoys, and depicting greater structural detail. These are cues the USCG/EA simulator does not now offer.

The information provided abeam differed for the two simulations. The available vertical image abeam was different because of differences in bridge dimensions. The CAORF bridge is approximately 30 feet wide (rail to rail), allowing the pilot to see only 5.4 degrees from the horizon to the top of the rail. The USCG/EA bridge is approximately 16 feet wide (rail to rail), allowing the pilot to see 10.6 degrees from the horizon to the top of the rail. These relationships are shown at the top of Figure 15. It may be noted that a 17-foot high buoy, 250 feet abeam of ownship with an eye height of 45 feet will fall from -6.4 degrees to -10.2 degrees below the horizon. This is shown at the bottom of Figure 15. Thus, the buoys are visible abeam on the USCG/EA simulation, but they were not visible abeam on the CAORF simulator when the ship is in the center of a 500-foot channel.

The bow images differed for the two simulations. The bow image was higher at CAORF, as if the ship were trimmed with the bow higher in the water. This means that the bow image took up more of the center screen and appeared closer to the horizontal demarcation between the sea and sky, and closer to the distant buoys



VWC = 2.53 cos (t + to) ft/sec

Figure 12. Current Speed Functions for the CAORF and USCG/EA Simulations

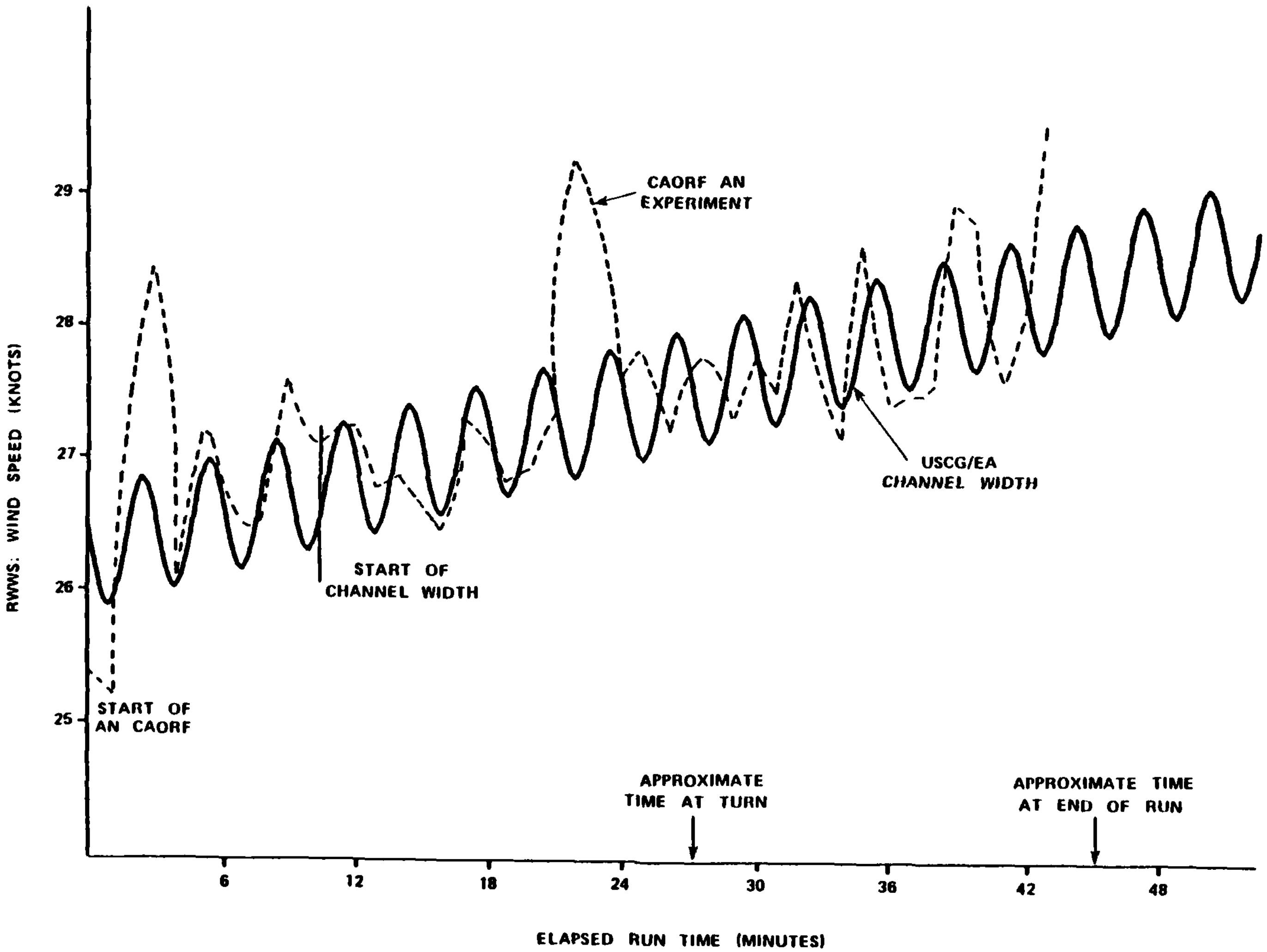


Figure 13. Wind Speed Functions For the CAORF and USCG/EA Simulations

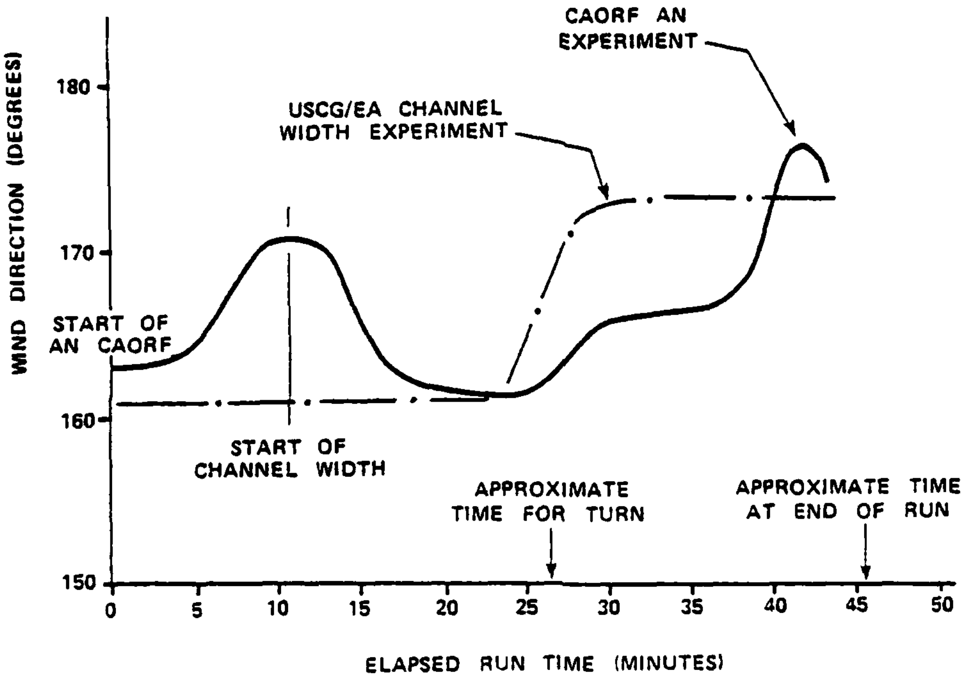


Figure 14. Wind Direction Function for the CAORF and USCG/EA Simula-ions

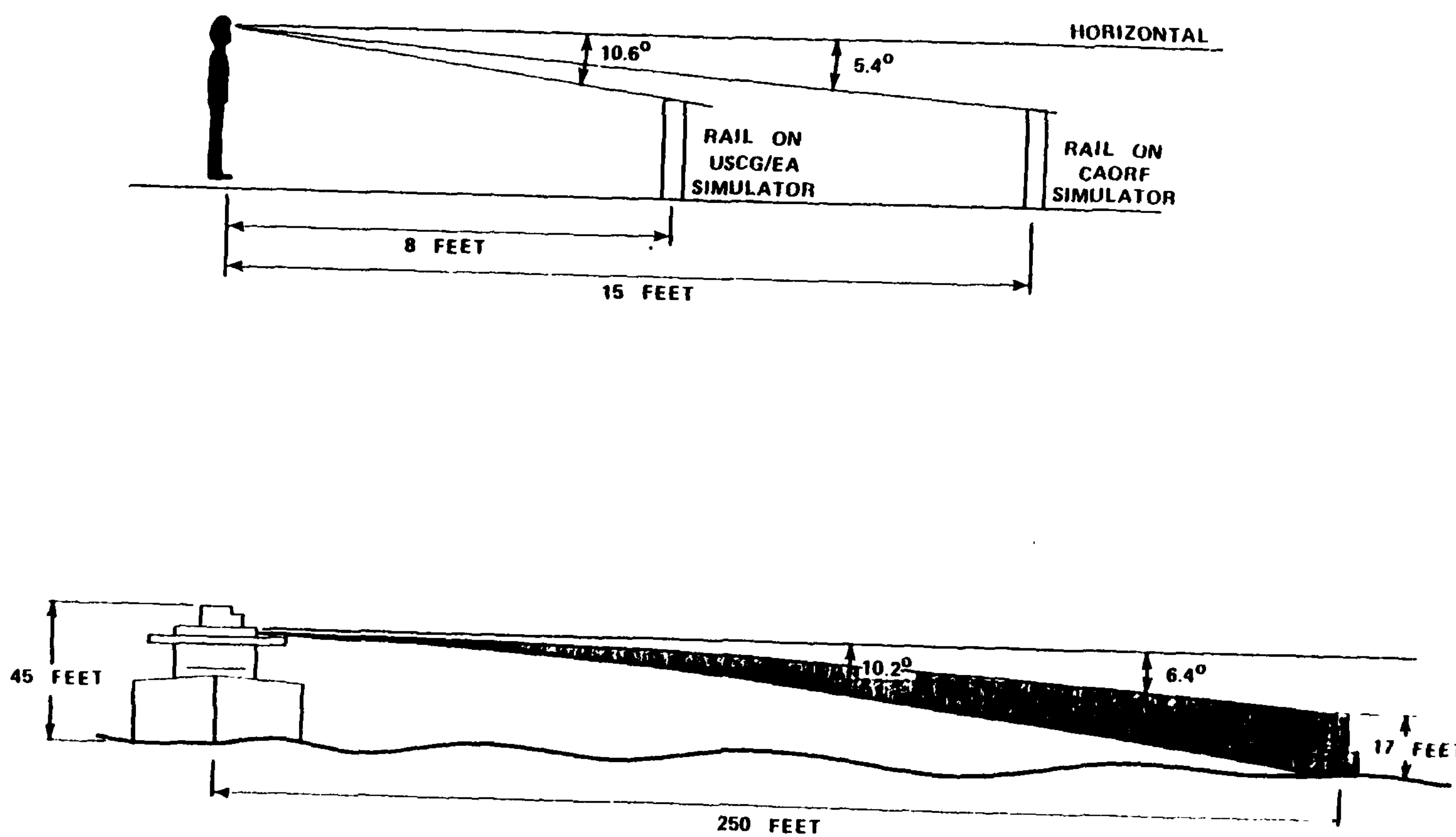


Figure 15. Vertical Images Abeam on the CAORF and USCG/EA Simulations

high on the screen. The bow image at USCG/EA appeared lower on the screen, as if trimmed down at the bow, and was visually farther from the buoys. The silouettes of the two bow images are compared in Figure 16.

3.2 THE REPLICATION OF THE STRAIGHT CHANNEL MARKING BY SPACING INTERACTION

The straight channel marking by spacing interaction was chosen for replication because of its importance to channel design. For the same reason, it was appropriate to choose the interaction to compare performance in (or performance of) the two simulations: CAORF and USCG/EA.

The values chosen to represent the interaction as measured in the two simulations are summarized in Table 8 and Figure 17. The CAORF values come from the four combinations of straight channel marking (staggered versus gated) and spacing (5/8 versus 1-1/4 nm) at 1-1/2 nm detection range. Each combination contains four scenarios that differ in day/night and turn characteristics. The scenarios included are described in Table 9. (It was necessary to pool day and night performance because of the nature of the CAORF design, which did not include all possible combinations of conditions. Daytime data alone would have meant that two of the combinations included only three buoy turns while two included only one-buoy turns. Since there was evidence in that experiment that, under some conditions, the effects of buoys in the turn lasted a considerable distance into the Leg 2, this confounding was not acceptable. Since performance was generally worse under nighttime conditions, the values selected here can be considered an overestimation of daytime standard deviations. The pooled turn characteristics are balanced in that all turn conditions appear in all straight channel combinations. It should be noted that the CAORF scenario pools contain turns that are substantially easier than the USCG/EA turn; that is, 15 degree and cutoff turns. This means the CAORF measures contain less of a potential effect of turn differences on the following straight channel performance.) The USCG/EA values come from those four combinations as discussed in Section 2. The constants there were 1-1/2 nm detection range, daytime, and 35-degree noncutoff three-buoy turns. From both experiments, the numbers are maximum standard deviation in Leg 2 after Data Line 11 and the mean at that point. Values that are different from each other at the 0.05 level of significance are indicated in Table 8.

TABLE 8. THE STRAIGHT CHANNEL MARKING BY SPACING INTERACTION FROM THE TWO SIMULATIONS

USCG/EA		Staggered	Gated
Spacing	5/8 nm	69	66
	1-1/4 nm	103	85
CAORF		Staggered	Gated
Spacing	5/8 nm	54	43
	1-1/4 nm	67 ⟷	43

⟷ Differences with $p \leq 0.05$

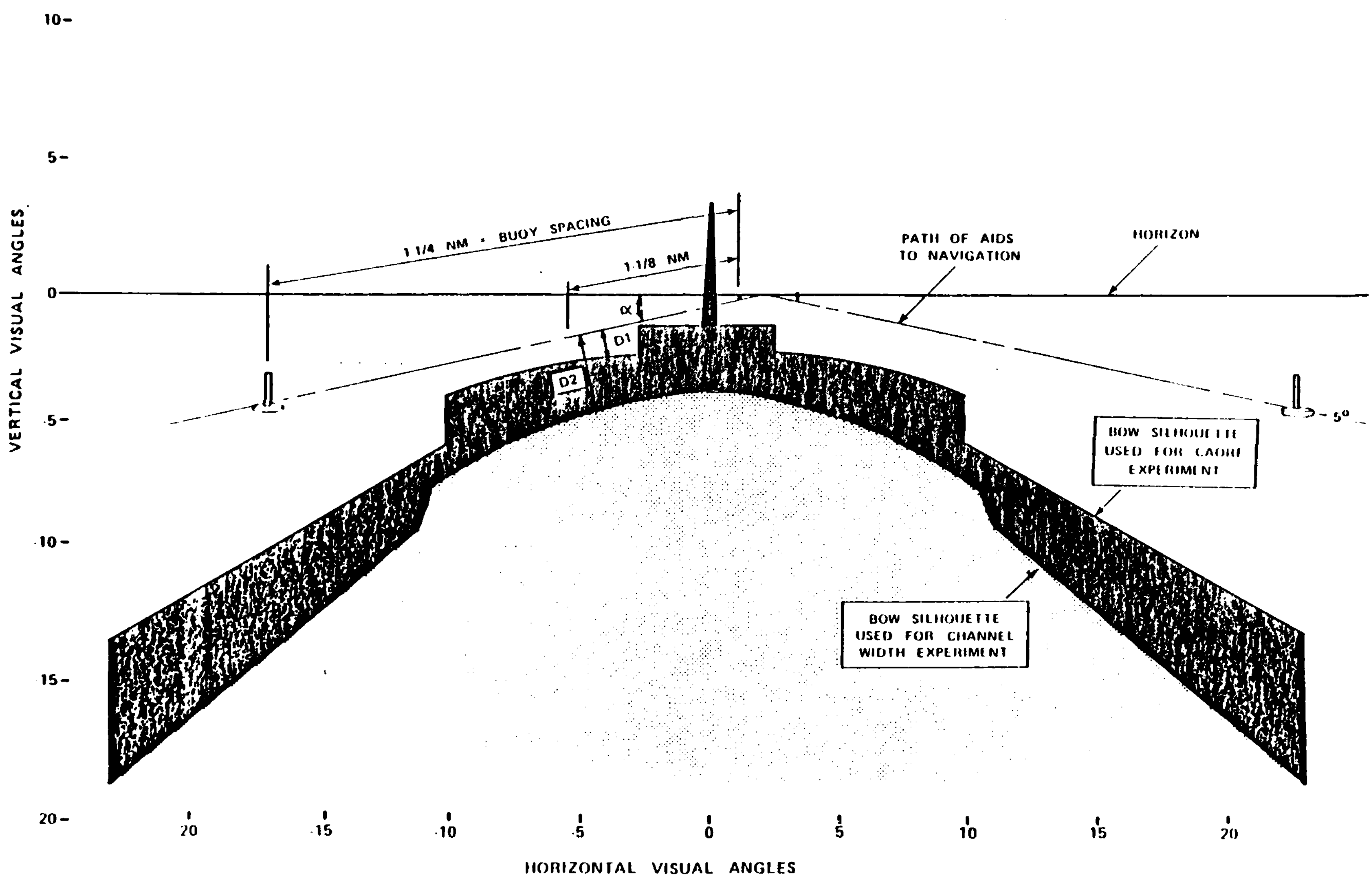


Figure 16. The Silhouettes of the Bow Images used at CAORF and for the USCG/EA Simulation

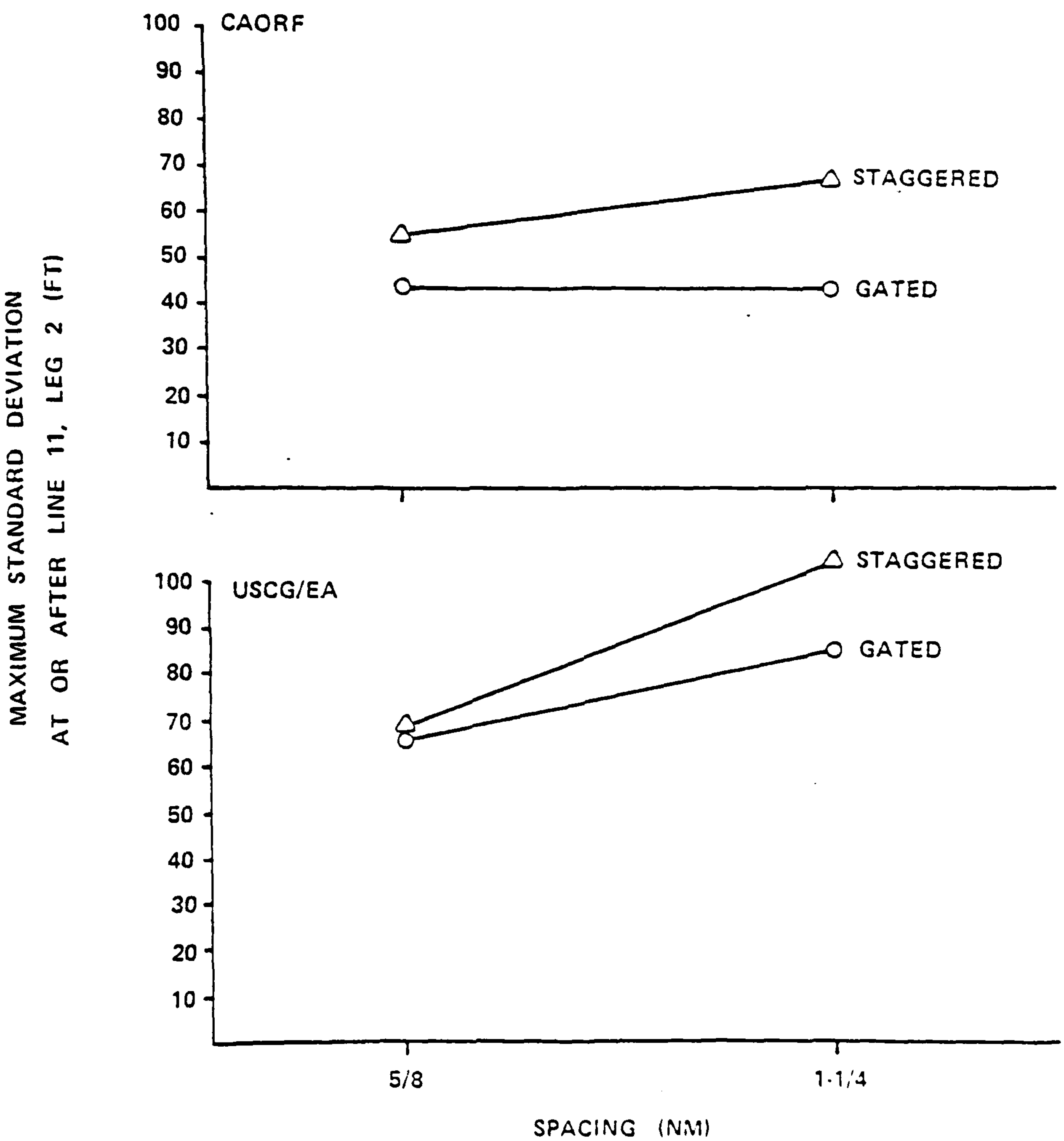


Figure 17. The Straight Channel Marking by Spacing Interaction from the CAORF and USCG/EA Simulations

TABLE 9. THE CAORF SCENARIOS CONTRIBUTING TO THE STRAIGHT CHANNEL MARKING BY SPACING INTERACTION

Scenario	Straight Channel Marking	Spacing	Turn-marking	Day/ Night	Detection Range	Angle of Turn (Degrees)	Turn Radius
2	Staggered	5/8 nm	1	N	1-1/2 nm	15	Noncutoff
9			3	D		15	Cutoff
17			3	D		35	Noncutoff
26			1	N		35	Cutoff
4	Staggered	1-1/4 nm	3	N	1-1/2 nm	15	Noncutoff
11			1	D		15	Cutoff
19			1	D		35	Noncutoff
28			3	N		35	Cutoff
6	Gated	5/8 nm	3	N	1-1/2 nm	15	Noncutoff
13			1	D		15	Cutoff
21			1	D		35	Noncutoff
30			3	N		35	Cutoff
8	Gated	1-1/4 nm	1	N	1-1/2 nm	15	Noncutoff
15			3	D		15	Cutoff
23			3	D		35	Noncutoff
32			1	N		35	Cutoff

The two simulations agree on the following:

- Staggered buoys result in larger standard deviations than gated.
- 1-1/4 nm spacing results in larger standard deviations than 5/8 nm.
- The effect of spacing is greater for staggered than gated buoys.

They disagree on the numbers – the magnitude of the standard deviation. The standard deviations are larger overall for the USCG/EA simulation than for the CAORF. Possible reasons for this discrepancy are discussed in Section 3.3.

3.3 COMPARISONS OF SCENARIOS

Four individual scenarios were chosen from the CAORF experiment that were most similar to the first four scenarios in the channel width experiment. The conditions for these four scenarios are listed in Table 10. These are the four combinations of straight channel marking and spacing with the constants of day, 1-1/2 nm detection range, 35 degrees, and noncutoff turn. Notice that two of the scenarios have one buoy in the turn rather than the three buoys that were constant in the turn for the channel width experiment. The exact combinations needed did not exist in the fractional design used at CAORF. Plots of performance for these individual scenarios appear as Appendix E. On those plots the approach to and pullout from the turn for Scenarios 19 and 21 are shaded to indicate the lack of comparability with the channel width scenarios. As single scenarios they are based on six runs each with some missing runs. Similar plots for these channel width

TABLE 10. THE CAORF SCENARIOS CHOSEN FOR COMPARISON TO THE CHANNEL WIDTH SCENARIOS

Scenario	Straight Channel Marking	Spacing	Turn-marking	Day/Night	Detection Range	Angle of Turn (Degrees)	Turn Radius
17	Staggered	5/8 nm	3	D	1-1/2 nm	35	Noncutoff
19	Staggered	1-1/4 nm	1	D	1-1/2 nm	35	Noncutoff
21	Gated	5/8 nm	1	D	1-1/2 nm	35	Noncutoff
23	Gated	1-1/4 nm	3	D	1-1/2 nm	35	Noncutoff

scenarios 1 through 4 are available in their set of plots for that experiment.[12] Those plots are based on eight runs each.

Performance in those CAORF scenarios can be described by the following statements.

- In Leg 1, all conditions are good with the staggered, 1-1/4 run spacing condition showing the widest band; the gated 5/8 nm spacing condition showing the narrowest band.
- In Leg 1, the staggered conditions show a tendency to approach an available buoy when maneuvering.
- Performance in the turn and pullout shows the effects of available buoys.
- Overall performance in Leg 2 is only slightly poorer than Leg 1 once the poorly marked pullouts are disregarded.
- In Leg 2, there are no large differences among the four conditions under daytime and long detection range conditions.
- In Leg 2, the gated, 1-1/4 nm spacing condition with its long distance without a buoy alongtrack shows the latest return to the centerline; however, the standard deviation is not large during that interval.

Comparing performance over the scenario for the two simulations, both agree that the band gets wider:

- As the ships maneuver.
- For staggered buoys.
- Where there are gaps in the buoys.
- For longer spacing.
- With the perturbation of Leg 2.

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[12] Eclectech Associates. Preliminary Performance Data AN Visual Channel Width Track Plots. U.S. Coast Guard, Washington, D.C., October 1980, pp. 1.1-11 to 1.1-14 and 2.1-11 to 2.1-14.

Performance on Leg 2 is generally poorer for the USCG/EA simulation than for CAORF. For the USCG/EA simulation, there is an increase in the standard deviation midway in Leg 2 that did not appear at CAORF. This increase is meaningfully related to buoy information. It is greatest where information is scantiest – the 1-1/4 nm spacing conditions are worse than the 5/8, and the 1-1/4 nm staggered condition is the worse of all. Performance in this last condition is illustrated in Figure 18. The logic that has developed in this project is that difficulty in the piloting task leads to dependence on buoy information and reveals differences in the adequacy of buoy information. This means that this increase must be the result of either increased difficulty – perturbation – or decreased buoy information. The explanation for this relatively poorer performance in the USCG/EA simulation is one or more of the differences listed in Section 3.1 above. These will be examined one by one.

1. A difference between the two pilot populations is an unlikely explanation because there was no meaningful difference in Leg 1 or the pullout. It was in the pullout that they were allowed to choose their own strategy.

2. It is unlikely that experimental design differences could have an effect only in Leg 2 and primarily in two of the four conditions. If such circumscribed effects had been possible, the homogeneous scenarios of the USCG/EA simulation would have resulted in smaller, not larger, standard deviations. The within-subjects design might have sharpened differences among conditions in that simulation, but it would have been neutral to their overall magnitude.

3. The ship hydrodynamics were the same.

4. The principal difference in environmental effects was the difference in wind direction discussed earlier and illustrated in Figure 14. Wind direction shows its greatest difference after the turn, the same portion of the channel where the biggest difference in performance was observed. However, it is unlikely that it is the major cause of the performance differences. First, the physical perturbation itself is small: the difference in wind direction was 7 to 10 degrees, causing a difference in turning moment of only 15 percent. Second, while this wind remains constant in Leg 2, the effect on performance is transient. Figure 18 may be inspected as a sample: while there is an increase in the standard deviation in Leg 2, there is also a decrease before the end of the run. (The force of this argument is somewhat decreased by the presence of a buoy at the end of the run.) It is unlikely that this increase in perturbation is the principal cause of the performance difference seen.

5. The visual effects offer some possible causes for the difference. The poorest performance occurred in the USCG/EA simulation in that portion of the scenario where the pilot is disadvantaged by the crosscurrent and the resulting drift angle, and in those scenarios that have the poorest buoy information. It is logical that that combination would make the piloting process vulnerable to any further loss of buoy information due to the characteristics of the simulation.

It could be that with the drift angle and fewer, less advantangeously-placed buoys, the difference in depth cues offered by the two simulators became more important. But at the distances involved, 1/4 to 1-1/4 nm from buoys, the distance cues are not so different between simulations, since the visual images of the buoys are extremely small. Nevertheless, the future development of the USCG/EA simulator should include added detail for the buoys or any distance objects.

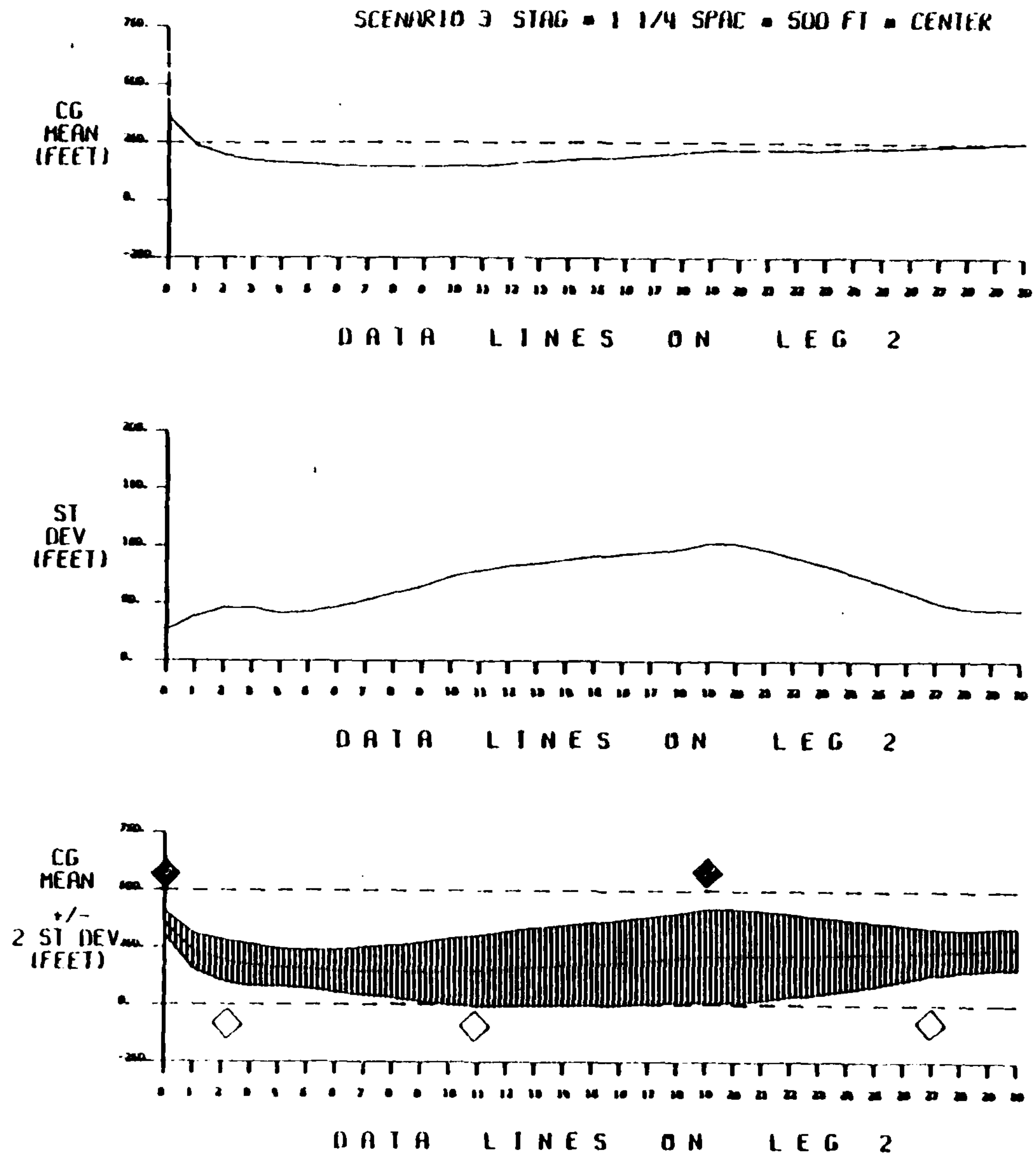


Figure 18. Performance in the 1-1/4 NM, Staggered Condition in Leg 2

It could be that with the drift angle and fewer, less advantageously-placed buoys, the view abeam became more important. If the pilots made greater use of the buoys abeam under such circumstances, the USCG/EA simulation's better view abeam might have a beneficial effect on the USCG/EA performance relative to performance at CAORF. This beneficial effect cannot explain the observed increase in standard deviation.

The difference in bow images is another potential source of differences in performance under difficult conditions. To use the bow image in explaining the observed performance, a number of assumptions must be made about the piloting process.

- The pilot's estimation of his crosstrack position is central to the process. (This has been assumed from the beginning of the project.)[13]
- Given long spaced, staggered buoys, he estimates his crosstrack position primarily by estimating the distance to the nearest buoy as it moves closer and passes a beam. (The observed tendency to "zigzag" in this experiment supports this assumption.)
- In a simulator, it is the visual distance or visual angle that is estimated.
- He is more accurate estimating shorter distances than longer. (This was observed in a CAORF experiment preceding the AN project.[14])
- A constant amount of change is more easily detected when the base value is smaller. (This is Weber's law, a classic of psychophysics.[15])

Given these assumptions, the differences between the two bow images illustrated in Figure 16 can be used to suggest a cause for the difference in performance. In estimating crosstrack position generally and the distance to the nearest buoy specifically (D1 and D2), the pilot using the larger bow image is advantaged in that he must judge the shorter distance D1 at CAORF versus the longer distance D2 for the USCG/EA simulation. This advantage lasts for long segments of the run; as shown in Figure 16, the high forecastle of the CAORF bow allows estimation of changes in D1 to be used for 1-1/8 of the 1-1/4 nm between the buoys. This makes detection, estimation, and compensation in the difficult crosscurrent situation relatively easier in the CAORF simulation. As the crosscurrent decreases, the advantage to the larger bow image decreases and so does the observed difference in

[13] W.R. Bertsche et al. Study of the Performance of Aids to Navigation Systems - Phase I, An Empirical Model Approach. U.S. Coast Guard, Washington, D.C., CG-D-36-78, July 1978.

[14] Eclectech Associates. Restricted Waterways Experiment IIIB Results and Findings. U.S. Coast Guard, Washington, D.C., May 1978.

[15] T. Engen. "Discrimination and Detection," in J.W. Kling and L.A. Riggs (Eds.) Woodworth and Schlosberg's Experimental Psychology. Third Edition, New York, Holt, Rinehart and Windston, 1971.

performance because the pilot then "splits" buoys with the jackstaff. This is a perceptual task which does not rely on the estimation of D1 or D2. Simulator performance at the end of Leg 2 is therefore more comparable.

The next experiment in the AN project – the ship variables experiment – will test these hypotheses. That simulation will:

- Attempt to match the CAORF wind conditions in Leg 2 more closely.
- Include simulated bridge wings which will prevent the pilot from watching and using the buoys abeam.
- Compare performance with the CAORF and Channel Width bow images.

If these hypothesized mechanisms are indeed the effective simulation differences, USCG/EA performance in the difficult conditions and the resulting maximum standard deviations should more closely approximate the CAORF performance.

3.4 SUMMARY AND CONCLUSIONS

The comparison of the two simulation/simulators has implications for the course of the AN project. Statements of relationships or differences among tested conditions can be obtained with either simulation/simulator. The CAORF and channel width experiments both support the following conclusions.

- Performance without perturbation is better than performance with it.
- Perturbation determines dependence on information differences.
- Gated buoys generally support more precise performance.
- Short spacing (5/8 nm) generally supports more precise performance than long spacing (1-1/4 nm).
- Performance with staggered buoys is more dependent on spacing than that with gated buoys.

With either simulation, comparison of shiphandling performance in the simulator with that at sea is necessary to provide guidance in correctly interpreting results before the preparation of design manuals or implementation in real world ports.

Section 4

PERFORMANCE AS A FUNCTION OF THE STRAIGHT CHANNEL MARKING BY CHANNEL WIDTH COMPARISON

The deterioration in performance with channel width was not proportional to the increased space available, suggesting that wide channels are not a special piloting problem or, therefore, a special design problem.

4.1 THE EFFECT OF CHANNEL WIDTH ON PERFORMANCE

Performance deteriorated slightly with channel width. Representative data to illustrate this deterioration are summarized in Table 11. The values are the maximum crosstrack standard deviation in each leg and the mean at that point. For these data that are pooled over staggered and gated conditions with increased channel width, the increase in displacement of the mean from the centerline and the increase in the standard deviation was small. The displacements of the means were compared with the t-tests; the standard deviations were compared as variances with F-tests. Changes in channel width did not cause statistically significant changes either in the displacement of the mean from the centerline or in the size of the standard deviation. The adequacy of performance at both channel widths is illustrated in Figure 19, which shows the combined plot (the mean with two standard deviations to either side against the channel boundaries) for both channel width conditions in Leg 2. With very similar means and standard deviations in the two conditions, there is more clearance between the bend and the channel edge in the wider channel. Performance is almost as precise with the extra space the wider channel allows.

4.2 THE COMBINATIONS OF CHANNEL WIDTH AND STRAIGHT CHANNEL MARKING

The effect of channel width was not the same for staggered and gated conditions. Most of the relationships summarized in Table 12 show expected differences in the 800-foot channels.

- Both the displacements of the mean and the size of the standard deviation were greater in Leg 2 than Leg 1.
- In Leg 1, both the displacement of the mean and the size of the standard deviation were greater for wide channel than for narrow channels and for staggered conditions than for gated.

TABLE 11. THE MAIN EFFECT OF CHANNEL WIDTH
(ENTRIES ARE IN FEET)

Conditions		Leg 1	Distance Offtrack	Leg 2	Distance Offtrack
500 feet	Mean	249	1R	199	51R
	Maximum standard deviation	52		93	
800 feet	Mean	413	13L	311	89R
	Maximum standard deviation	66		87	

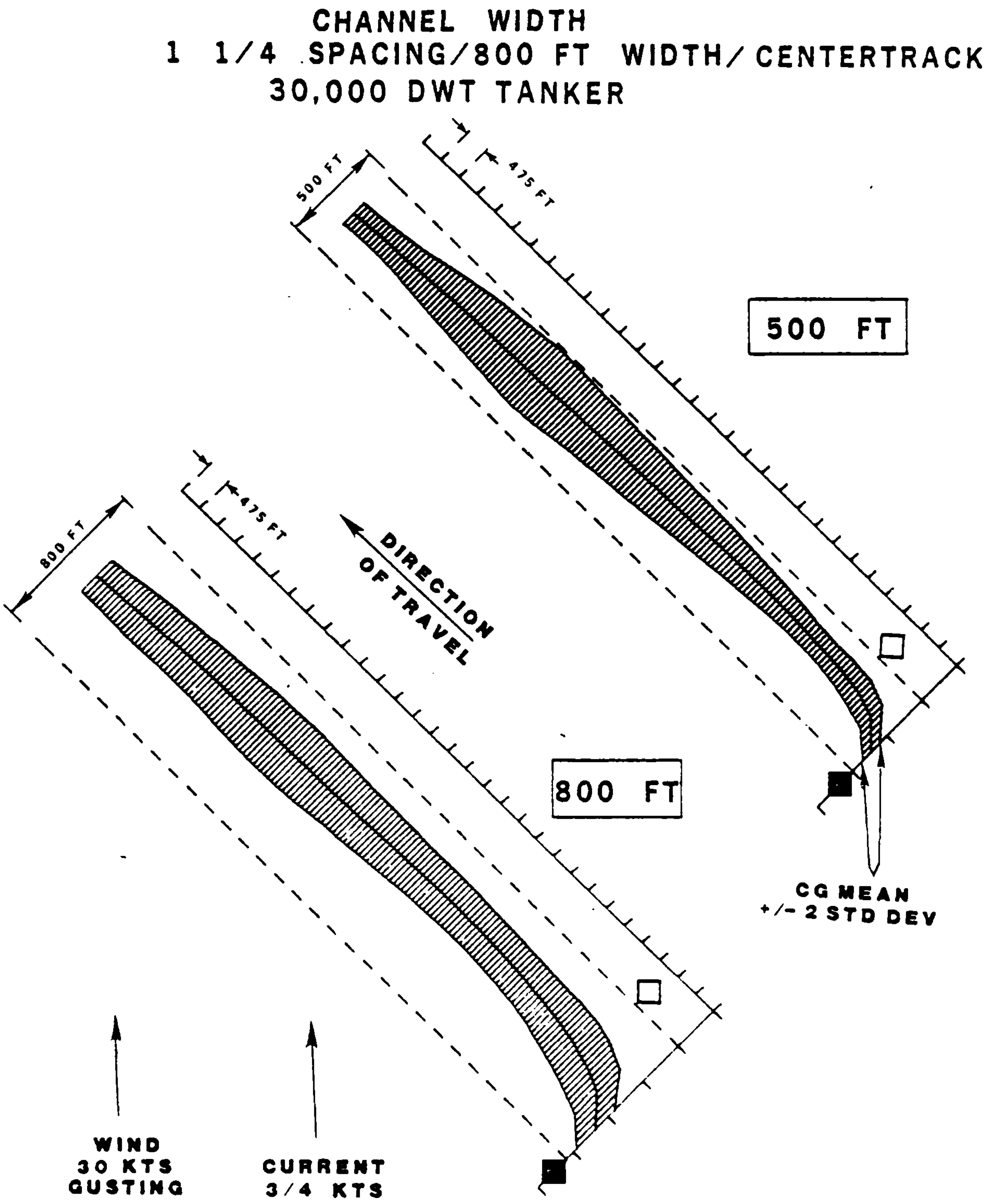


Figure 19. The Effect of Channel Width on Performance in Leg 2

TABLE 12. THE EFFECTS OF CHANNEL WIDTH AND STRAIGHT CHANNEL MARKING (ENTRIES ARE IN FEET)

Conditions		Leg 1	Distance Offtrack	Leg 2	Distance Offtrack	Difference Between Legs
500-foot width, staggered	Mean	255	5L	218	32R	37
	Maximum standard deviation	65		103		
500-foot width, gated	Mean	246	6R	181	69R	63
	Maximum standard deviation	40		85		
800-foot width, staggered	Mean	430	30L	320	80R	110
	Maximum standard deviation	69		72		
800-foot width, gated	Mean	398	2R	305	95R	93
	Maximum standard deviation	61		107		

- In Leg 1, both the displacement of the mean and the size of the standard deviation were greater for wide channel than for narrow channels and for staggered conditions than for gated.
- In Leg 2, the displacement of the mean was greater both for wide channels and for staggered configurations.

However, in Leg 2 the relationship among the standard deviations is not intuitive. These standard deviations are repeated in Table 13 for comparison. None of the differences are significant, but they are worth discussing because they are not expected.

There seem to be two different processes contributing to the interaction. First, for the staggered buoys, the standard deviation decreased rather than increased with channel width: from 103 to 72 feet. Something good happened to the piloting as it was done with staggered buoys when the channel width increased. Discrete changes in the effectiveness of piloting have usually signaled a change in strategy; that is the case here. The change in performance with staggered configurations as channel width increased is illustrated in Figure 20. The mean of the transits shifts further away from the centerline with the wider channel. Notice that both mean tracks approach the centerline from the right at the point at which there is a buoy on the left. (Only the buoys for the 800-foot channels are drawn in the figure: the alongtrack distance is the same for both conditions.) It is at that point that there is the maximum crosstrack standard deviation for both channel widths. This peak is higher for the 500-foot channels. The helm orders plotted in Figures 21A and 21B show the difference in strategies. For the 500-foot channels some of the pilots approach the buoy on the far side, improving the mean but increasing the standard deviation. (This strategy was discussed in Section 2.2.) For the wider channel, they did not do this. Apparently, they were satisfied with a less precise crosstrack position in the wider channel and did not find it necessary to "zigzag."

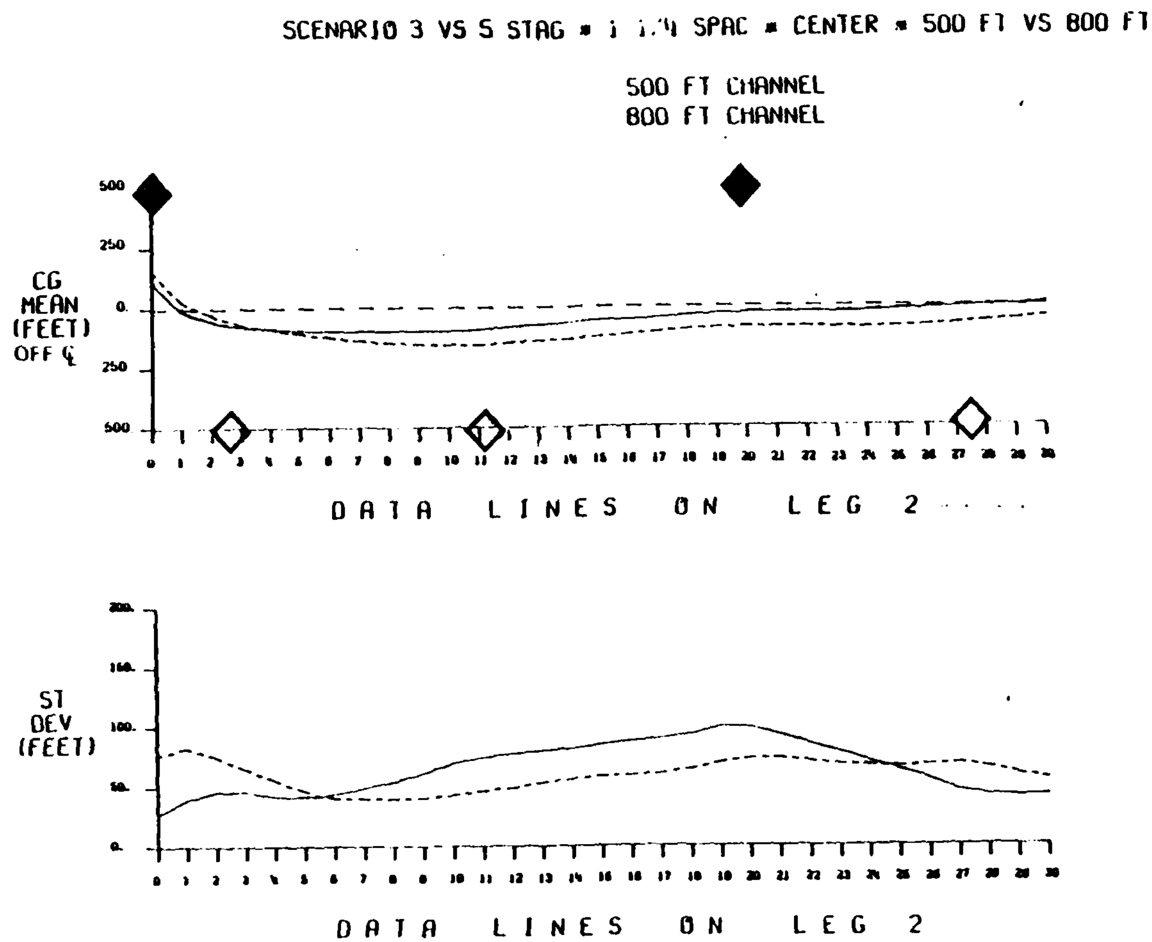


Figure 20. Change in Performance for Staggered Configurations with Channel Width

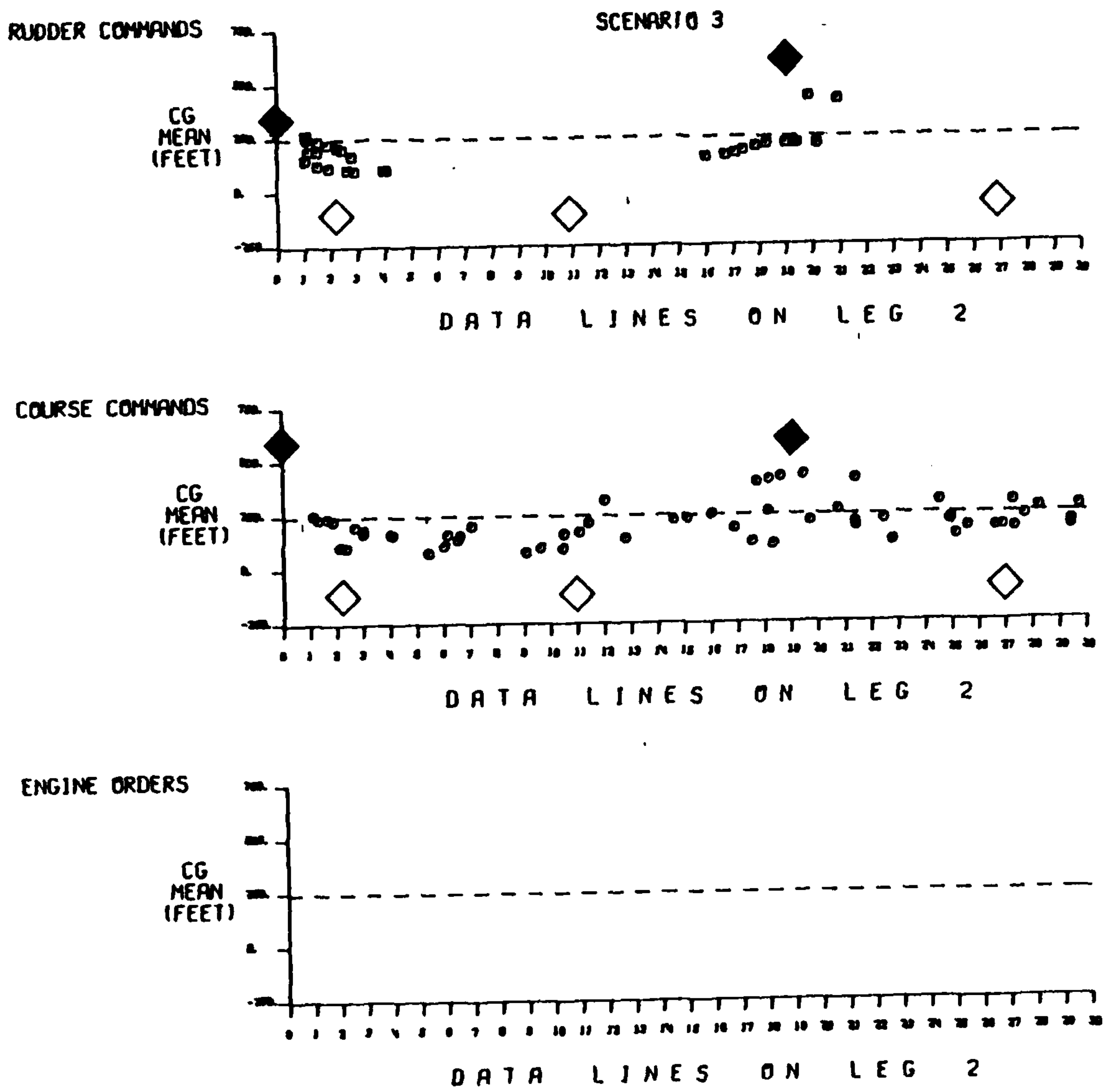


Figure 21A. The Helm Orders in Leg 2 for the Staggered Condition with a 500-Foot Channel

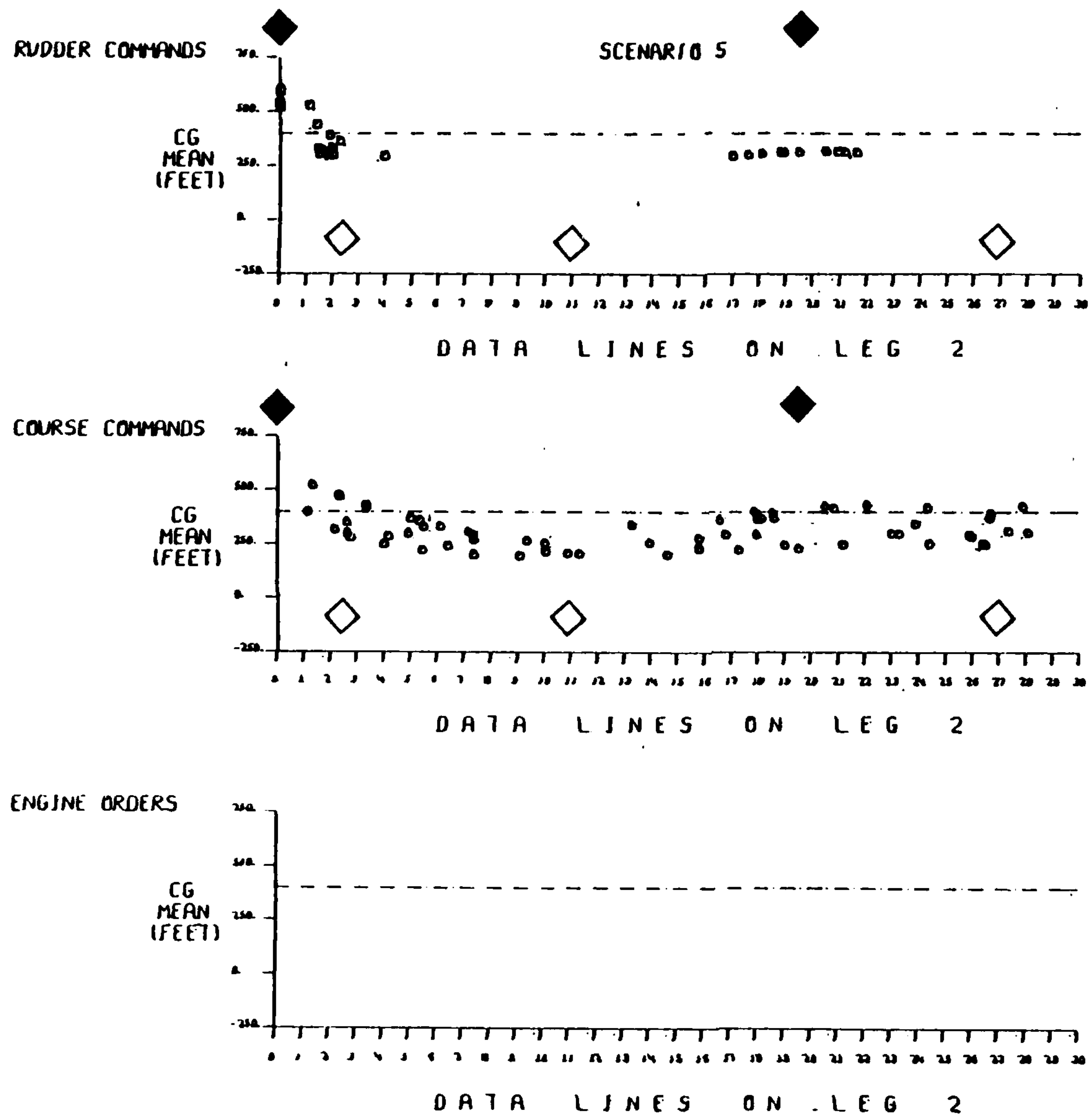


Figure 21B. The Helm Orders in Leg 2 for the Staggered Condition with an 800-Foot Channel

TABLE 13. THE CHANNEL WIDTH BY STRAIGHT CHANNEL MARKING INTERACTION AS INDEXED BY THE MAXIMUM STANDARD DEVIATION IN LEG 2 (IN FEET)

	Staggered	Gated
500 feet	103	85
800 feet	72	107

Consequently, the standard deviation was smaller for that condition. This change in strategy illustrates again the nature of the relationships between channel conditions and piloting performance. Changes in conditions do not always lead to gradual or continuous changes in the pilots' ability to achieve their goals or strategies, but sometimes to a change in those strategies.

There still remains the question of why the standard deviation is larger for the gated buoys than for the staggered – 107 feet as compared to 72 feet. This difference contradicts the generality that gated buoys are better than staggered. Figure 22 shows that the large standard deviation comes between gates, where the pilots had no close buoys. There was a similar but lesser effect with the 500-foot channel: the corresponding maximum standard deviation was 85 feet. The generality must be modified to allow for the channel width interaction. With narrow, 500-foot channels, where the standard deviation is more critical, gated buoys support better performance. With wider channels, performance with gated buoys deteriorates and loses its advantage; however, not to the extent that performance is inadequate in the wider channels.

An explanation of the differential effect of channel width on performance with gated or staggered buoys requires inferences about the processes the pilots use in the experimental situations. It was suggested in the CAORF final report[16] that there are two essentially different piloting processes. The pilots can concentrate on the buoys up ahead to locate a short-term goal and judge their relationship to it. Gated buoys encourage such a process: the jackstaff is used to "split the gates" up ahead. It seems reasonable that such a process would suffer with increased channel width. It is more difficult to "split" or find the midway point of a larger distance. Alternatively, the pilots can concentrate on the edges of the channel and judge their relationship to them. Staggered buoys seem less specialized. They seem related to a mix of the two processes with less simply interpretable performance resulting. It could be inferred from the performance observed here that with the narrow channel at least some of the pilots used the staggered buoys to locate the edges, approaching available buoys to enhance this judgment. With the wider channel, they abandoned this enhancement, either satisfied with their estimation of the edge from their position closer to the center or concentrating on the buoy ahead as they did with gated buoys.

It is possible to use these inferred processes to "predict" the interaction between channel width and straight channel marking. The concentration on the channel ahead encouraged by gated buoys is specially suited to trackkeeping in narrow

[16] Smith and Bertsche.

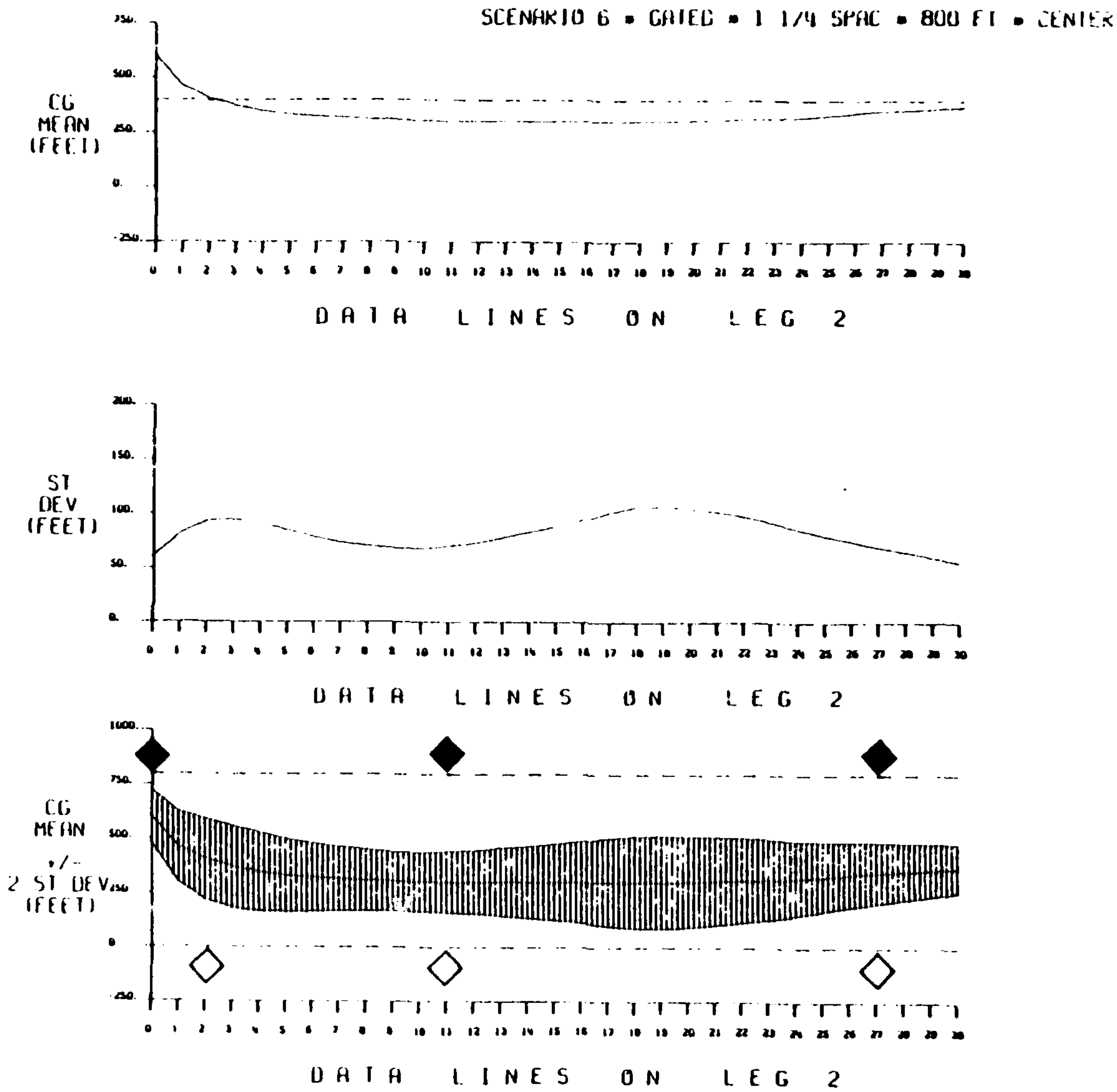


Figure 22. Performance in the Gated, 1-1/4 NM Spacing Condition with 800-Foot Channel Width

channels. Staggered buoys are less suited to trackkeeping in narrow channels and encourage a mix of strategies both between and within pilots, with more variable performance. Wider channels are actually a less difficult and more forgiving piloting problem. Therefore, the buoy configuration is less critical. Trackkeeping with gated buoys does deteriorate but not proportionally to the extra width; trackkeeping with staggered buoys is adequate whatever strategy the pilots choose to use.

4.3 SUMMARY AND CONCLUSIONS

With channel width the deterioration in performance was not proportional to the extra space available. The change in the displacement and width of the band, formed by the mean with two standard deviations to either side, with channel width, is illustrated in Figure 19 for Leg 2 where the displacement and width are always greatest. The greater clearance of the band for the wide channel suggests that wide channels were not a special problem in channel design – markings that were adequate for a narrow channel (500 feet) were adequate for a wider one (800 feet). This was true whether staggered or gated buoys were involved. By the same reasoning, it was not necessary to consider shorter spacing than the 1-1/4 nm used there: more precise performance than that obtained here would have been unnecessary. It is possible that longer spacing than that tested would be adequate in wide channels. Except for the possibility of research on this specific situation of long spacing in wide channels, further research can be restricted to the 500-foot channel.

Section 5

PERFORMANCE AS A FUNCTION OF THE STRAIGHT CHANNEL MARKING BY INTENDED TRACK COMPARISON

There was no meaningful change in the precision of performances with a change in the intended track from the centerline to the center of the right-hand side of the channel. With the right-hand track, the distribution of transits was, of necessity, closer to the right-hand edge of the channel; but there appears to be a compensating greater certainty about the location of that edge.

5.1 THE EFFECT OF INTENDED TRACK ON PERFORMANCE

When the pilots were instructed to make their transits of the channel at the center of the right-hand side rather than the centerline of the channel, their goal or intended track shifted. What was of interest was how well they were able to approximate each of those tracks. Representative data in Table 14 show there was a difference. The values are the maximum crosstrack standard deviation in each leg and the mean at each point. In addition, the table includes the difference of each mean from the intended track in each leg with and without the crosscurrent. With the centerline track the means were almost on the intended track in Leg 1, but were displaced 80 to 90 feet in Leg 2. On the other hand, with the right-hand track, the mean was less accurate in Leg 1 with a displacement at 60 to 70 feet, but was actually narrowed by the current in Leg 2. For each track, the observed mean was compared to the intended mean with a t-test for a single mean.[17] The results are indicated in Table 14. For the centertrack, the observed mean was not different from the intended track in Leg 1 but was in Leg 2. For the right-hand track, the results were reversed: the observed mean was different in Leg 1 but was not in Leg 2. (To compare an observed mean to an intended mean with a t-test is conceptually related to asking whether the intended mean is within the confidence interval – in this case, the 95 percent confidence interval – of the observed mean. If they are different, they are not within the same confidence interval.) The difference in the standard deviation for the two tracks were only trivally different; they were not statistically different and can be considered the same for the purposes of this discussion. The centertrack performance was more accurate with the following current in Leg 1 but suffered more from the crosscurrent; the right-hand track performance was less accurate with the following current but suffered less from the crosscurrent in Leg 2. (The difference between the centerline staggered and gated conditions in Leg 2 is discussed in Section 4.)

The clearance between the band and the right-hand side of the channel was by necessity different. This difference is illustrated in Figure 23 for Leg 2. There is less clearance with the right-hand track. This does not mean the right-hand track is a greater design problem. The greater accuracy of the mean – it was only 2 feet to the right of the true center of the right-hand side – suggests that the greater closeness to the edge was balanced by a greater certainty about the location of the edge or about the ship's relationship to that edge. According to these data, the right-hand track is not a special design problem or a special research problem. A

[17] McNemar.

TABLE 14. THE EFFECTS OF INTENDED TRACK AND STRAIGHT CHANNEL MARKING
(THE NUMBERS ARE IN FEET)

Condition		Leg 1	Difference From Track	Significance of Difference	Leg 2	Difference From Track	Significance of Difference
Center, staggered	Mean	430	30L	--	320	80R	*
	Maximum standard deviation	69			72		
Center, gated	Mean	398	2R	--	305	95R	*
	Maximum standard deviation	61			107		
Right, staggered	Mean	266	66L	*	198	2R	--
	Maximum standard deviation	44			66		
Right, gated	Mean	272	72L	*	169	31R	--
	Maximum standard deviation	69			64		

*Probability that difference occurred by chance is less than 0.05.

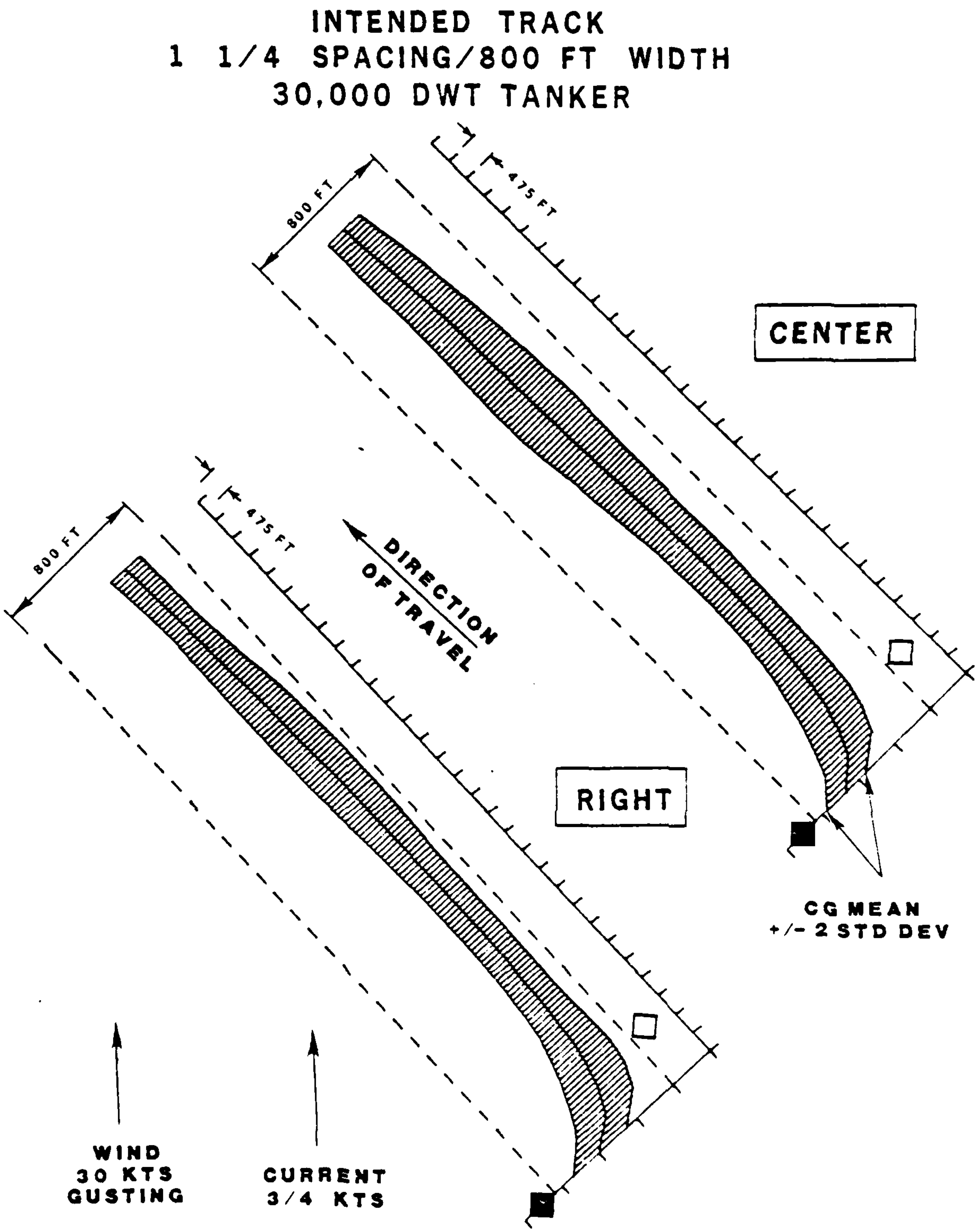


Figure 23. The Effect of Intended Track on Performance in Leg 2

channel that is adequately marked for a centerline track is adequately marked for a right-hand track.

5.2 THE RIGHT-HAND TRACK AND STRAIGHT CHANNEL MARKING

Included in this interaction is a comparison of right-hand track performance with staggered and gated buoy configurations. Performance was very similar with the two as illustrated by the representative data in Table 14. Performance in Leg 1 seems to show slight superiority for staggered conditions with a better mean and smaller standard deviation. These differences are not statistically significant. A reason for even this slight difference is shown in Figures 24A and 24B. The crosstrack location of the course orders in Leg 1 shows one pilot following the centerline rather than the right-hand track. This is an error in strategy, rather than perception: Figure 24B shows that he did not continue this error in Leg 2. In Leg 2 there are essentially no differences between staggered and gated conditions. Neither the means nor the standard deviations are significantly different. Figure 25 illustrates the placement of the distributions in the channels.

In Section 5.1 above, it was suggested that the right-hand track both required and allowed the pilots to concentrate on the right-hand edge of the channel. There is no difference between staggered and gated conditions in buoy information on the right-hand side. The resulting similarity in performance supports the conclusion that the pilots did indeed use the buoys to the right rather than those on both sides when on the right-hand side of the channel. These results suggest that in marking a channel to guide two-way traffic, there is no difference between staggered and gated buoys.

5.3 SUMMARY AND CONCLUSIONS

Piloting at the center of the right-hand side was not a special problem. This was true both without and with a crosscurrent. Without the crosscurrent, the crosstrack mean of the transits was less accurate than was the case with the centerline track. However, the standard deviation did not increase and the band formed by the mean with two standard deviations to either side did not go out of the channel boundaries. With the crosscurrent, performance at the right-hand half of the channel was actually more accurate. The right-hand track does not seem to be a piloting problem, a design problem, or a research problem.

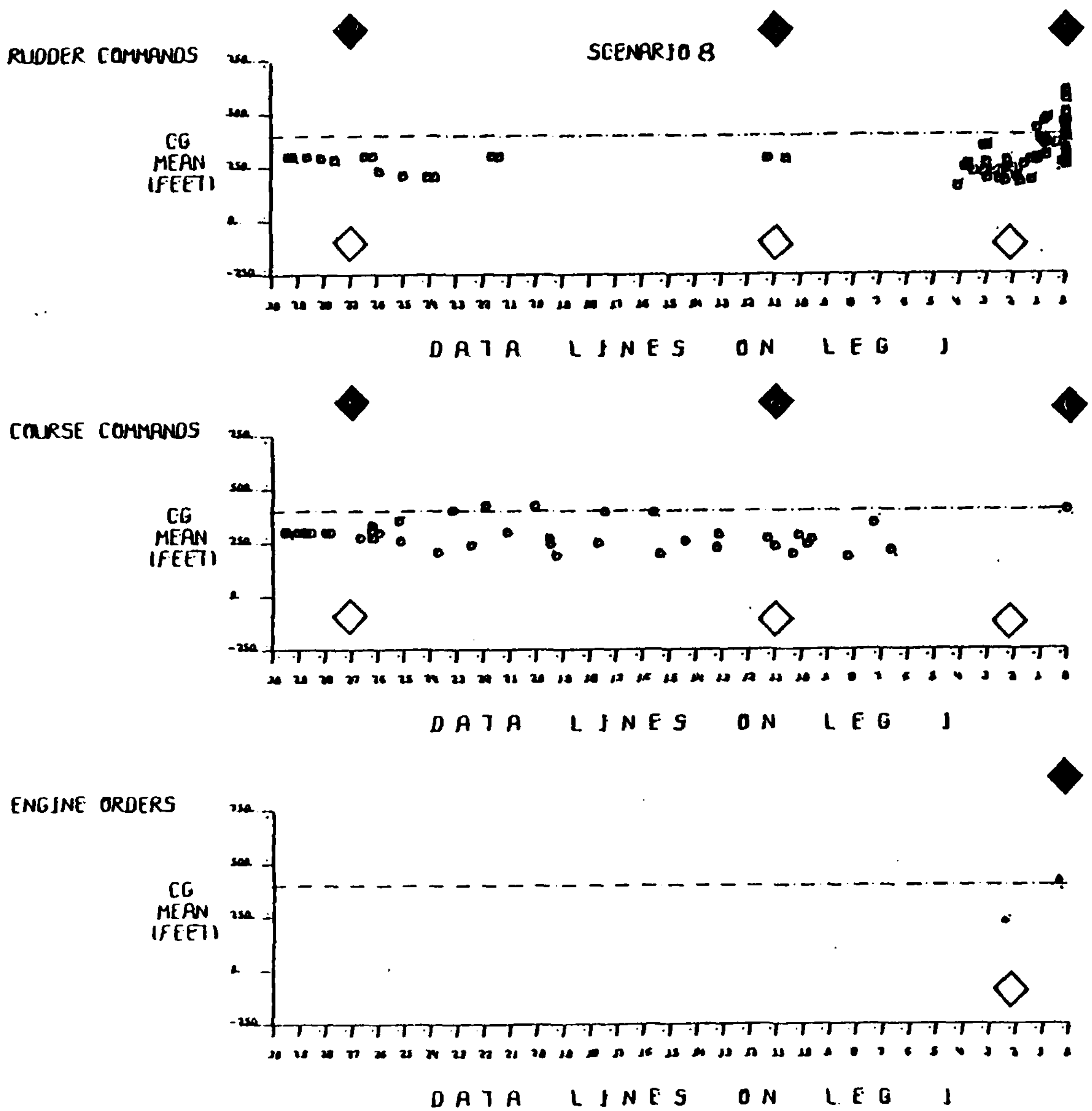


Figure 24A. Helm Orders for the Gated Right-Hand Track Condition in Leg 1

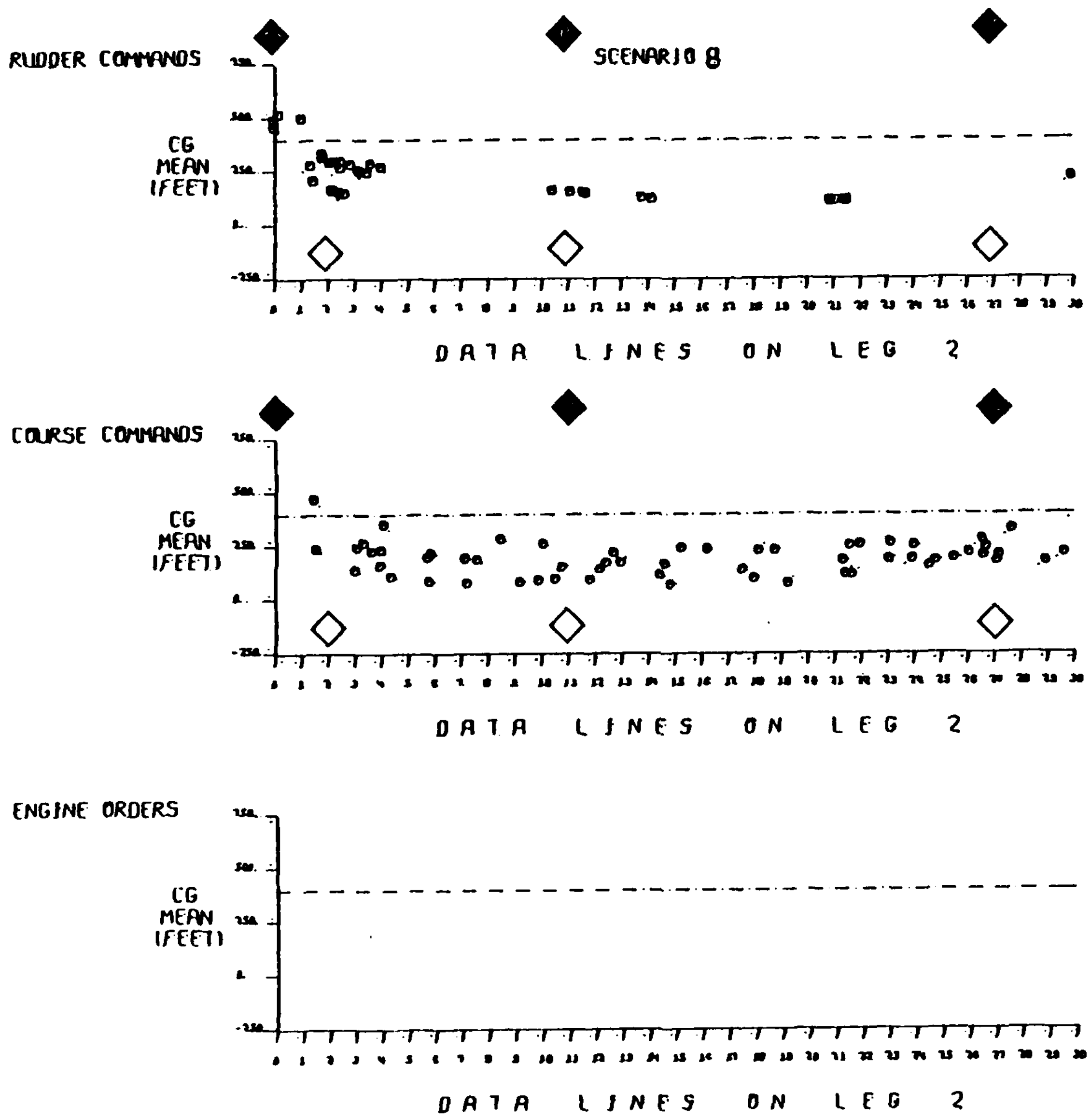


Figure 24B. Helm Orders for the Gated Right-Hand Track Condition in Leg 2

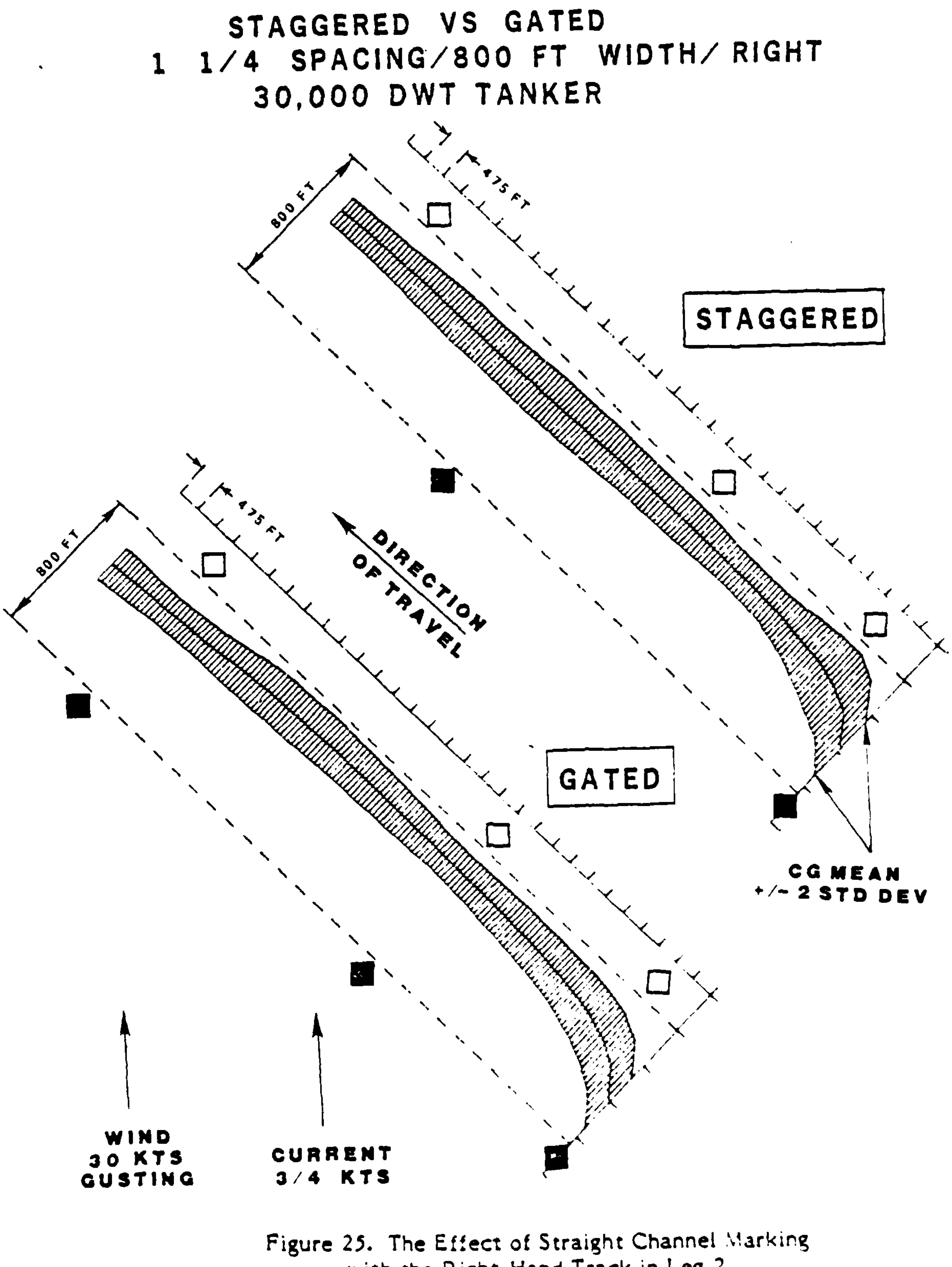
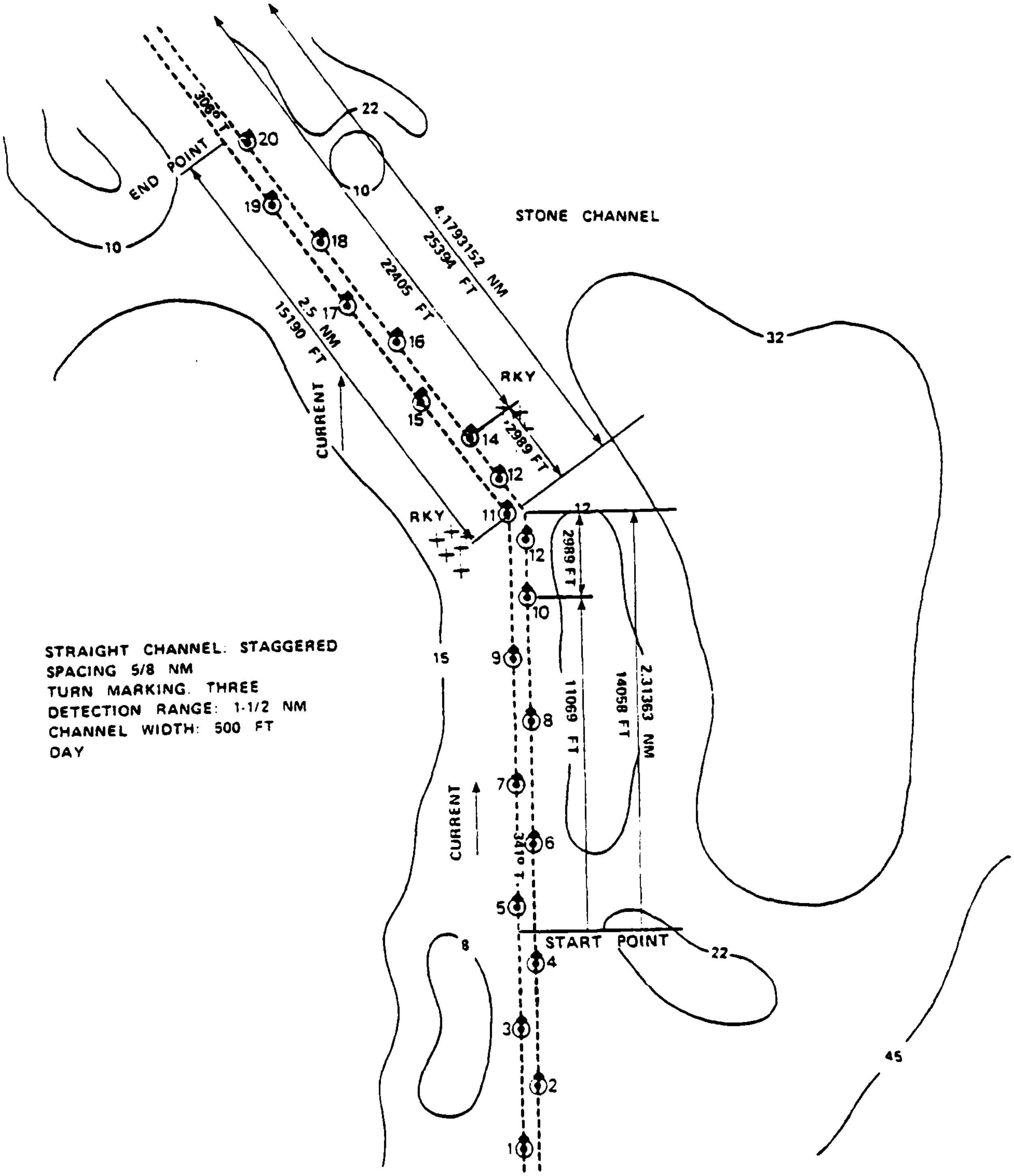


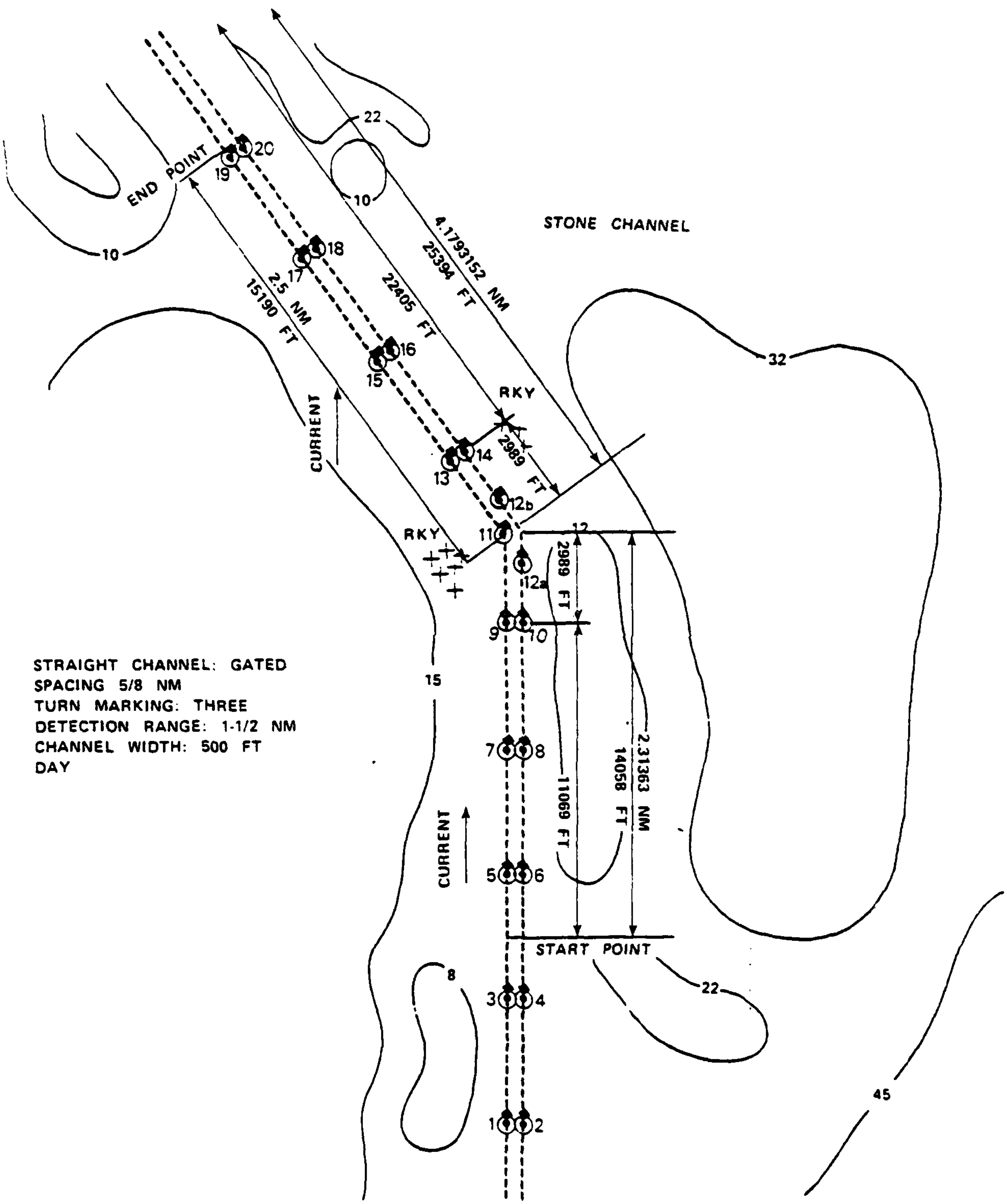
Figure 25. The Effect of Straight Channel Marking with the Right-Hand Track in Leg 2

APPENDIX A

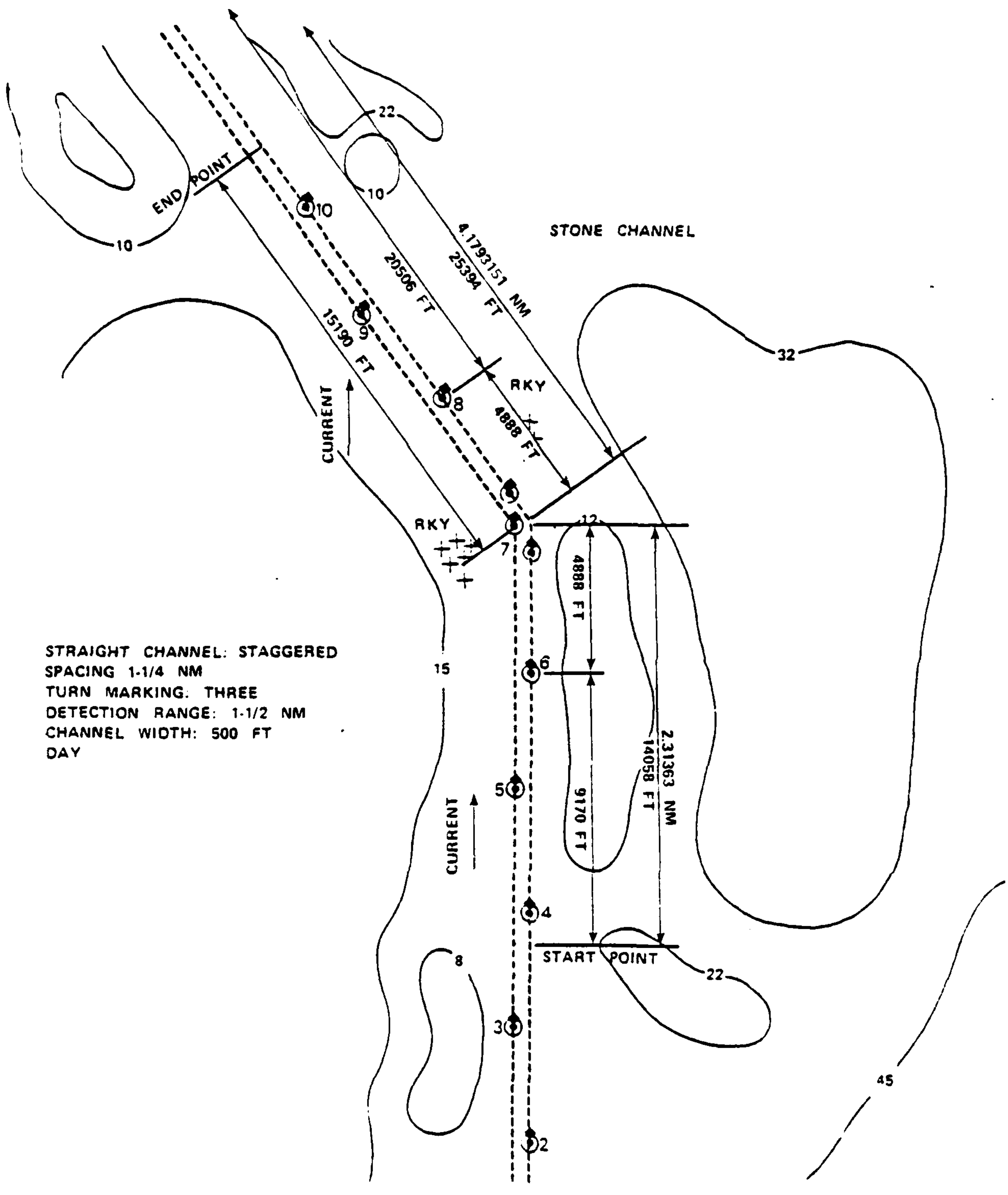
DIAGRAMS OF EIGHT INDIVIDUAL SCENARIOS



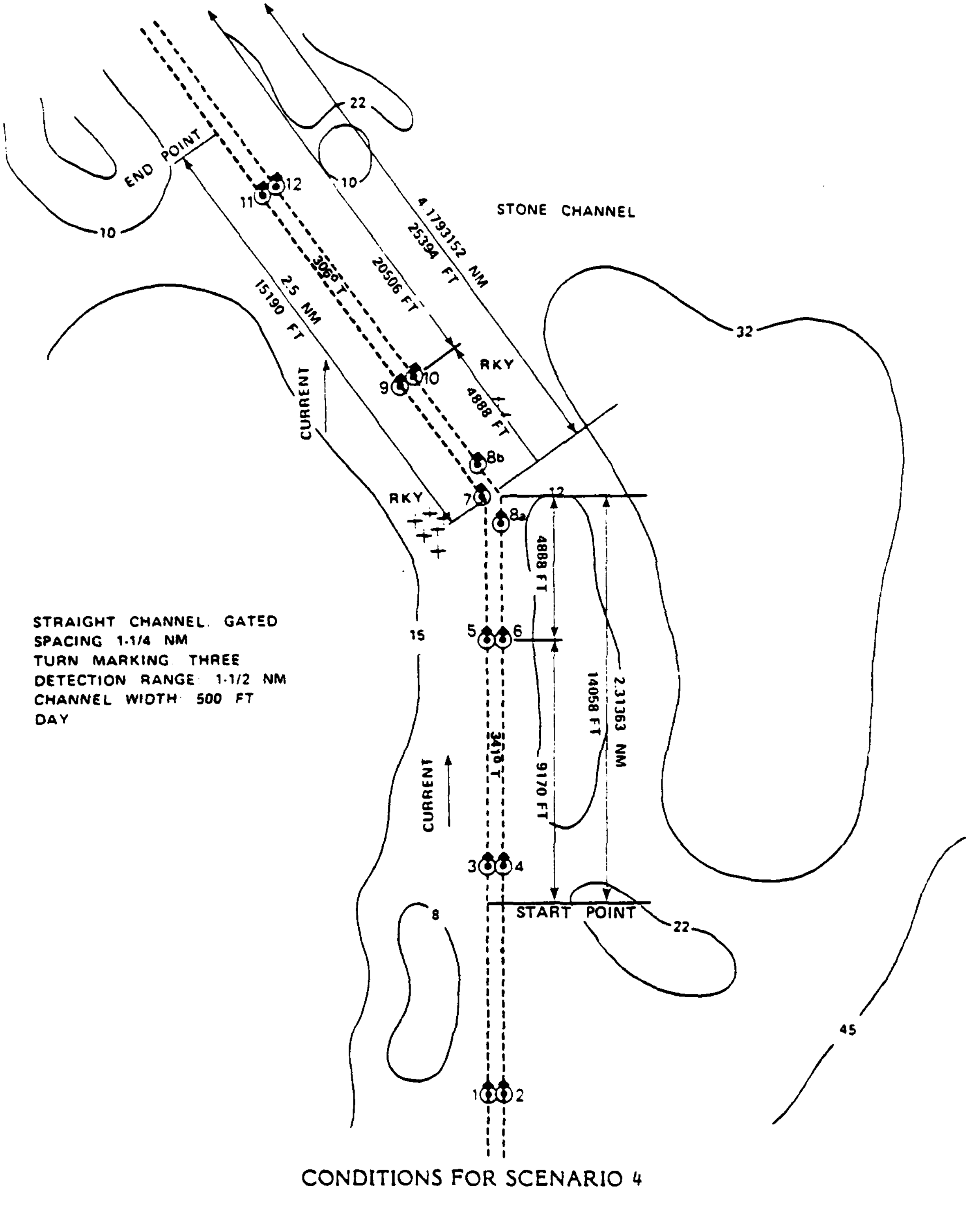
CONDITIONS FOR SCENARIO I



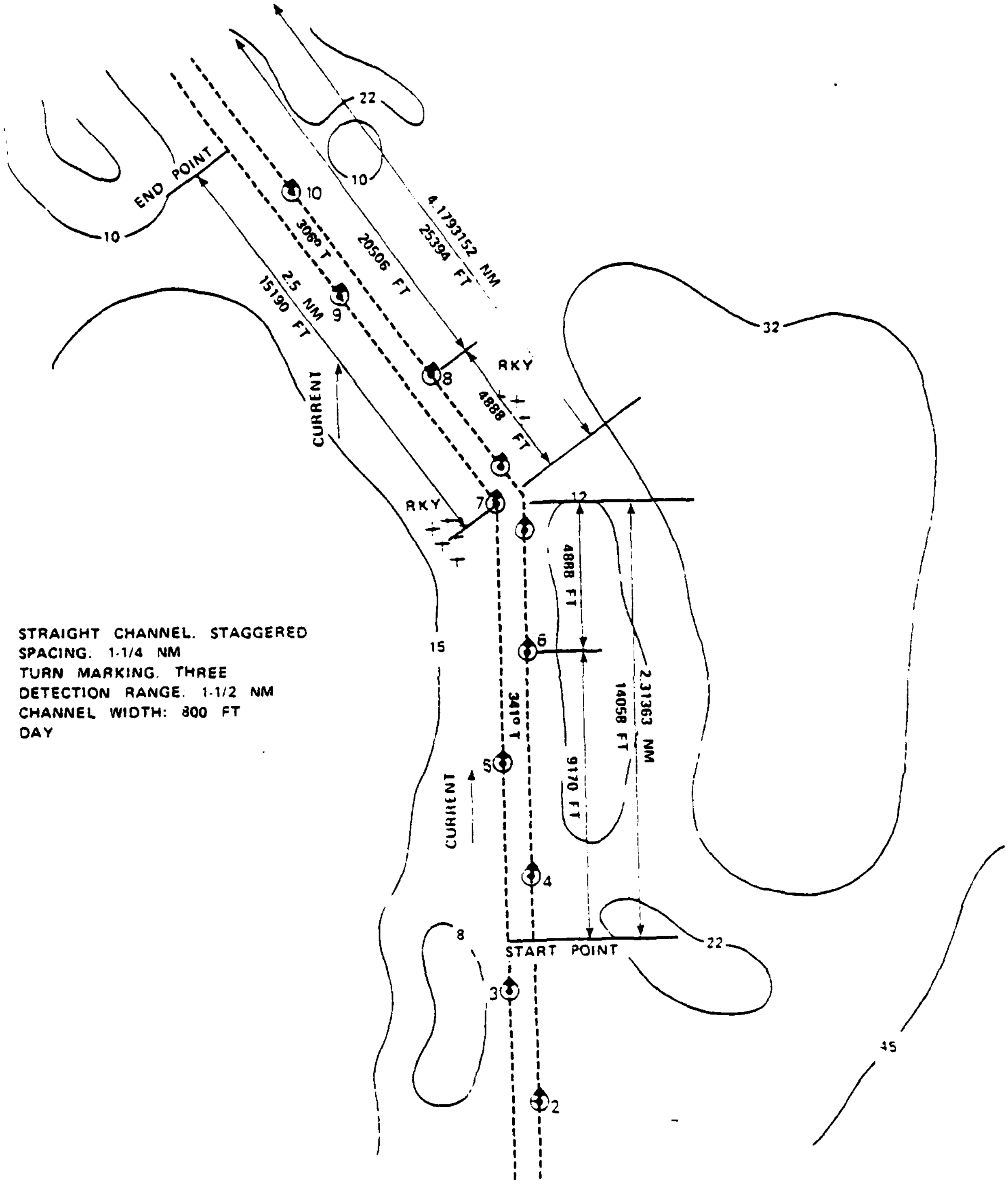
CONDITIONS FOR SCENARIO 2



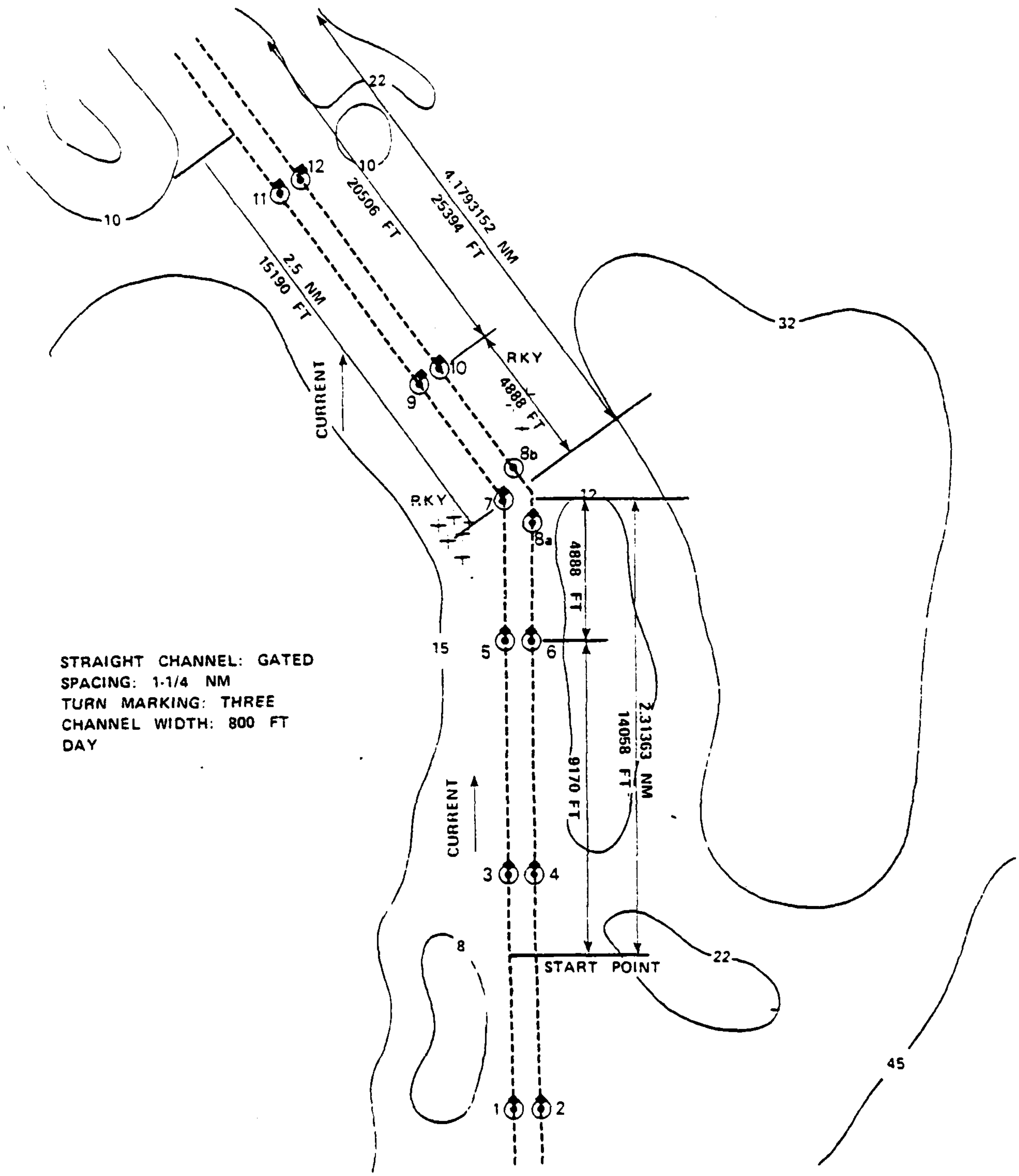
CONDITIONS FOR SCENARIO 3



CONDITIONS FOR SCENARIO 4



CONDITIONS FOR SCENARIOS 5 AND 7



CONDITIONS FOR SCENARIOS 6 AND 8

APPENDIX B

INSTRUCTIONS TO THE PILOT FOR THE AN-CHANNEL WIDTH EXPERIMENT

B.1 INTRODUCTION

The purpose of this experiment is the evaluation of the effect of channel width and available buoys on piloting performance. Channels 500 or 800 feet wide will be combined with staggered or gated buoys at different spacings. The effect of these factors on piloting performance in a narrow channel with a turn will be measured.

B.2 RUNNING OF THE SCENARIOS

1. There will be nine scenarios, each taking approximately 35 minutes to run.

2. There will be charts available for each scenario showing the configuration of the channel, and the turn and buoy placement. There will also be a diagram illustrating the current. (A sample is attached.)

3. Each scenario will begin slightly to the right of the center of the channel 2-1/3 nm below the turn and end 2-1/2 nm beyond the turn.

4. There will be a helmsman on the bridge to receive your orders.

5. Speed will be controlled by the EOT which will be set at SLOW AHEAD or 40 rpm at the beginning of the scenario. It is preferable that you maintain SLOW AHEAD. However, RPM changes are possible if you decide they are absolutely necessary for maneuvering. Return to SLOW AHEAD as soon as possible. The following variations are available:

	RPM	Knots
DEAD SLOW	20	3
SLOW	40	6
HALF	60	9
FULL	80	12

No ASTERN variations are available.

6. Since this is an experiment on visual effects, there will be no radar.

7. You will be furnished with a questionnaire at the completion of each scenario or at the end of the experiment which will permit you to report subjective impressions.

B.3 SPECIFICS COMMON TO ALL SCENARIOS

1. All scenarios will be run under daytime conditions. Visibility is 3 nm in the first run and 1-1/2 nm in all others.

2. Ownship is a 30,000 dwt tanker with a split-house configuration and a midships bridge. It has a 595-foot LOA, an 84-foot beam, a 45-foot height of eye, and a 34-foot draft. The bridge is 200 feet aft of the bow. The ship will handle as if it were in shallow water.

3. There will be a following current of approximately 1-1/4 knots at the beginning of the run. This current will decrease steadily while approaching the turn. After the turn, the current will be 3/4 knot broad on the port quarter. It will return gradually to follow the channel. A diagram is attached and is available on the chart table.

4. There will be a wind of 30 knots. The wind direction is from aft during the first leg and broad on the port quarter during the second leg.

5. The ship's speed will be 8 knots over ground at the beginning of the run. It will be controlled by the EOT which will be set at HALF AHEAD. It will decrease slightly as current speed decreases.

B.4 MANEUVERING INSTRUCTIONS

Ownship will be initialized at the point indicated on the chart for the scenario. It will be in the channel to the right at a distance from the center sufficient for passing a traffic ship. There will be three minutes for the helmsman to steady the ship on course and for you to observe before assuming control of the ship.

For Scenarios 1 to 6

What is important in this experiment is the help the buoys can give you in perceiving or knowing where you are in the channel. This is best evaluated at the center of the channel. When you take control, please go to the center as quickly as you think prudent. Try to stay within one-half of a ship's width of the center or as close to this as is practical regardless of the width of the channel. This is a real test of what the buoys in the scenario can do for you. You may leave the center to maneuver through the turn as soon as you judge it necessary. In the second leg please return to the center again as soon as possible and maintain it until the end of the scenario.

For Scenarios 7 and 8

Ownship will be initialized at the same point in the channel as for the other scenarios — to the right of center, 2-1/3 nm before the turn. For these two scenarios, please move further to the right-hand side of the channel as quickly as you think prudent. Try to stay within one-half of a ship's width of the center of the right-hand side or as close to this as is practical. Both scenarios to which this request applies are 800 feet wide. You may leave this trackline to maneuver through the turn as soon as you judge it necessary. In the second leg, please return to the trackline in the right-hand half of the channel again as soon as possible and maintain it until the end of the scenario.

B.5 PERCEPTUAL RESPONSES

1. There are arrangements for an extra measure of just how well the buoy arrangements can tell you of your position in the channel. There is a panel on the bridge with buttons for you to press to indicate your position relative to the designated trackline for the scenario. (See attached illustration.) The buttons will light up about once a minute. Please press one to indicate whether you are to the right, on the trackline, or to the left of the trackline. When you press a button, hold it down until the light goes off. If you do not press it, it will go off in 30 seconds.

2. If it is possible, please use a more precise definition of the trackline for these perceptual responses than for maneuvering the ship. When the buttons light up, use the buoys to determine where you are relative to the exact designated trackline for the scenario. (See attached illustration.) Press the "TL" button only when you consider yourself to be on the exact trackline. Press the "L" or "R" button when you consider yourself to be the left or right of the trackline. When you are not at the trackline because of maneuvering requirements, indicate your relationship to the trackline from wherever you are. It is not necessary to order a heading change because you indicated you are not on the exact trackline.

3. Please respond to the lights as frequently as possible, guessing if you think you have a chance of being correct. If you have no idea at all where you are and do not want to guess, do not press anything. The lights will go off in 30 seconds.

4. Please judge your position as accurately as you can each time. Make each judgment independently of the one before. It is not necessary to be consistent from one response to the next.

B.6 REPORT OF CROSSTRACK MOVEMENT

The help the buoys can provide you in judging crosstrack movement of the vessel is of interest too. Several times during each scenario, you will be asked to report your perception of crosstrack movement: whether to the left, to the right, or none. Please answer with your best estimate which will be recorded.

Please feel free to ask questions or make comments at any time.

APPENDIX C

POSTSIMULATION QUESTIONNAIRE FOR AN-VISUAL CHANNEL WIDTH EXPERIMENT

*1. The Simulation

- Did you find the simulation realistic/unrealistic?
  - View compatible with 45 foot height of eye and bridge 300 feet back?
  - Buoys in proper perspective from ship, in proper relationship to "horizon" line, right for visibility, spacing?
  - Ship's responsiveness: time for rudder angle indicator to respond, time for ship response, rate of turn, time to check swing?
  - Current and wind effects?

2. Familiarization

- Did the simulation seem easier over runs?
  - Using or reading buoys?
  - Shiphandling?
  - Responding to wind and current?
  - How fast did it become easier?
  - Did it become too easy?

*3. Strategy (perceptual/cognition and shiphandling)

- Did you perceive the ship to be right of center at initialization?
- Was the instruction to "try to stay within one-half of a ship's width of the center (or center of righthand side) or as close to this as is practical" a reasonable one?
- Describe your strategy for running through the scenario.
- How did you:
  - Establish your position at initialization?
  - Move to designated track?
  - Trackkeep?
  - Approach, execute, and recover from turn?
  - Return to center?
  - Adjust to decreasing crosscurrent?
- Did you make adjustments in your visual procedures because:

- It was a simulation?
- You were instructed to stay at center when practical?
- You were asked to report crosstrack position with response panel?

*4. Experimental Variables

- How did you adjust your strategy as described above:
  - For gated or staggered buoy?
  - Long or short spacing/high or low density of buoys?
  - Narrow or wide channel?
  - Center or right-hand track?

(Diagrams of the scenarios are attached.)

5. Position Estimation Techniques

- Describe how you estimate your position throughout the transit. (general question)
- Describe how you estimate your crosstrack position in straight legs?
  - What do you do when the buoys are ahead? Gated buoys?
  - Do you use the jackstaff in this proces? How?
  - In the real world, would you use any bearing devices in this process? (azmiuth, ring, pelorus) How?
  - What does the phrase "splitting the gates" mean to you?
  - Do you use the compass in this process? How?
  - Do you use the charted channel heading in this process? How?
  - Do you do anything specific when buoys pass abeam?
  - How do you estimate position when there are staggered buoys ahead? Abeam?
- Describe how you estimate your downtrack position for starting your turn (when do you start your turn)?
- Describe how you tell during a turn if the rate of turn is too fast or too slow or just right?

6. Perceptual Response Measures

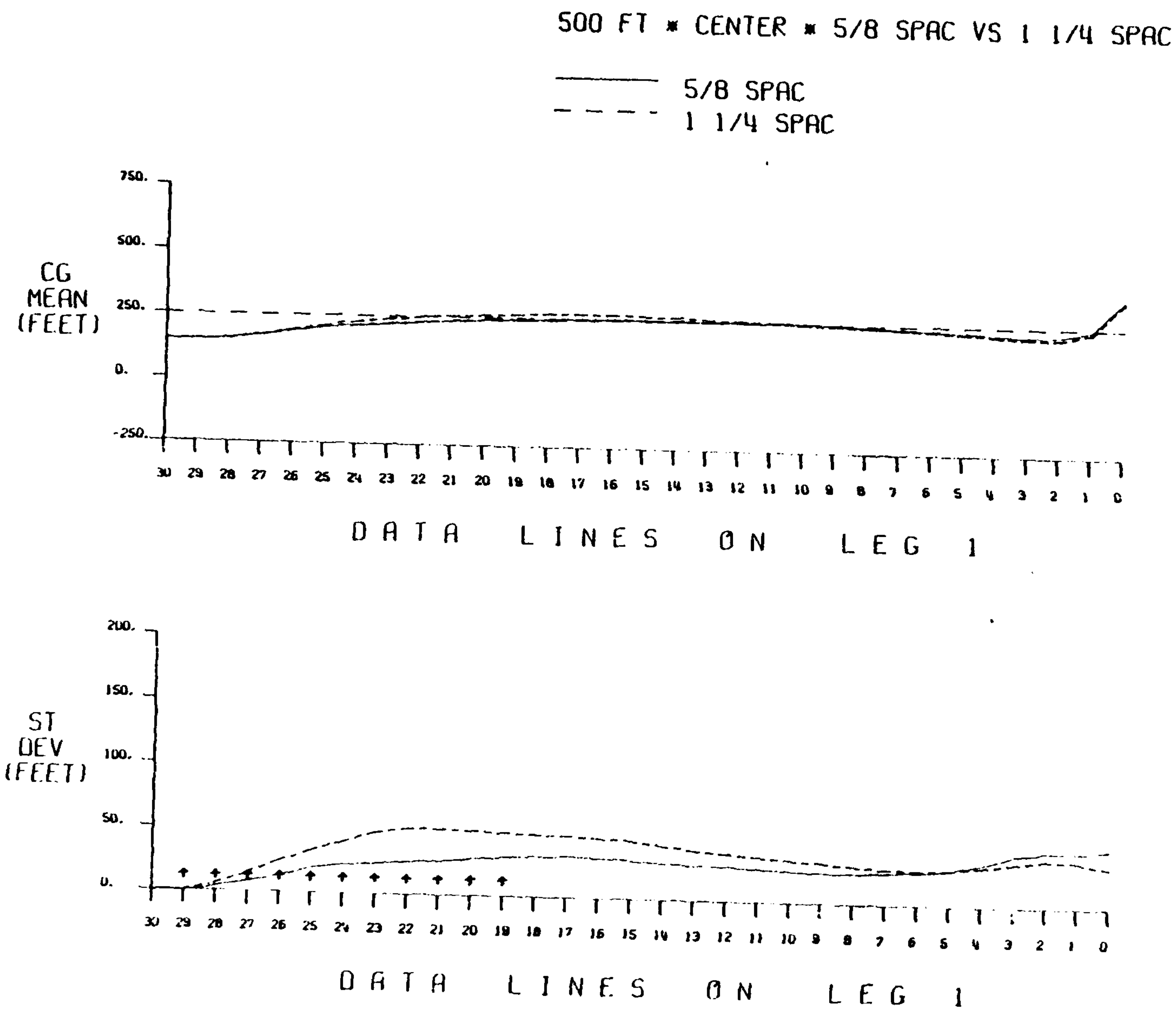
- Did you find the use of the response panel compatible/distracting with the way you think/pilot?

- How much guessing/certainty was involved in your responding? Under what circumstances?
  - Experimental variables?
  - Distances to buoys?
- Was it meaningful to make a distinction between a practical center for maneuvering and a precise center for the response panel?
- Perception of lateral set/crosstrack movement. (Repeat questions in this section)

Do you have other comments?

APPENDIX D

SIGNIFICANCE TESTS OVER THE SCENARIO FOR MAJOR COMPARISONS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DATA LINES ON LEG 1
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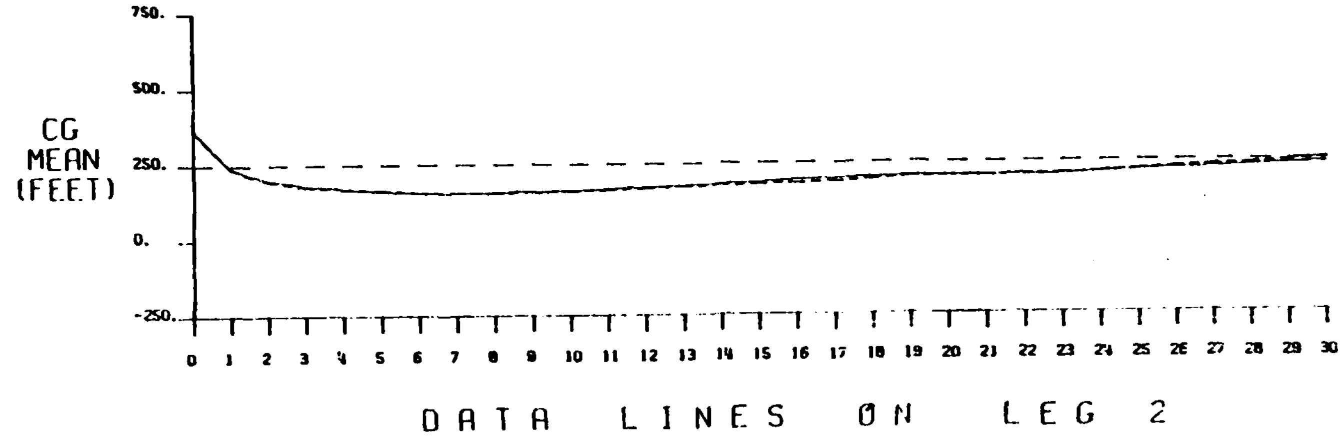
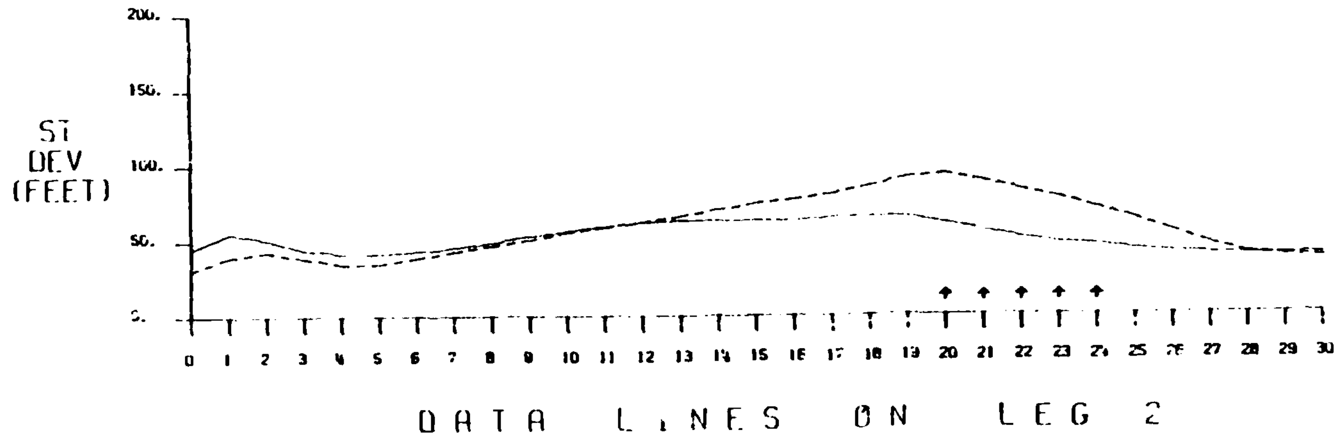
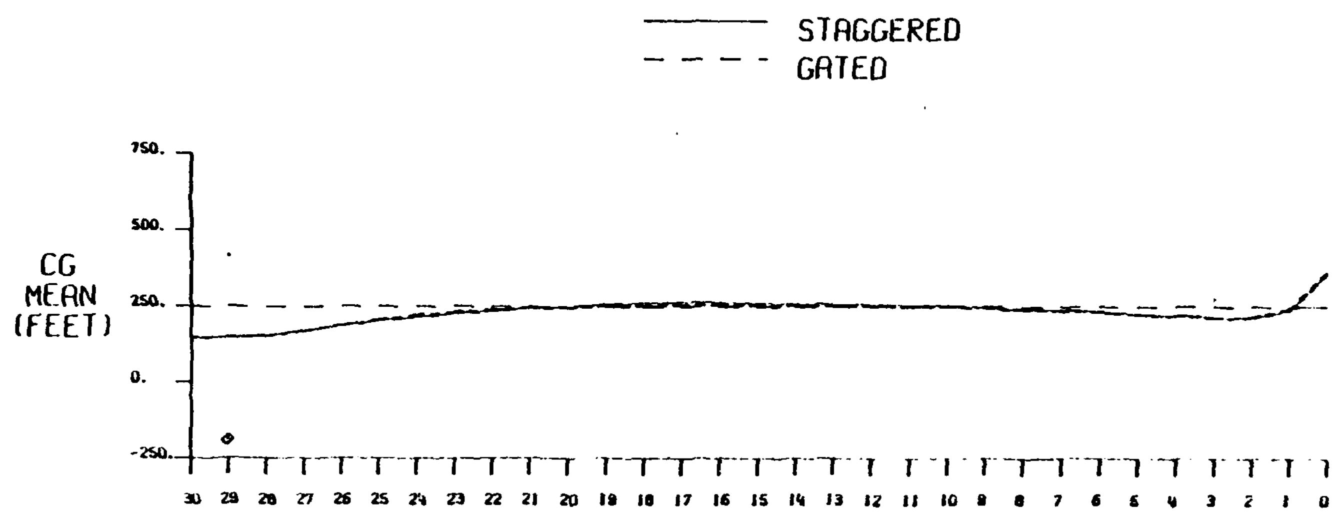
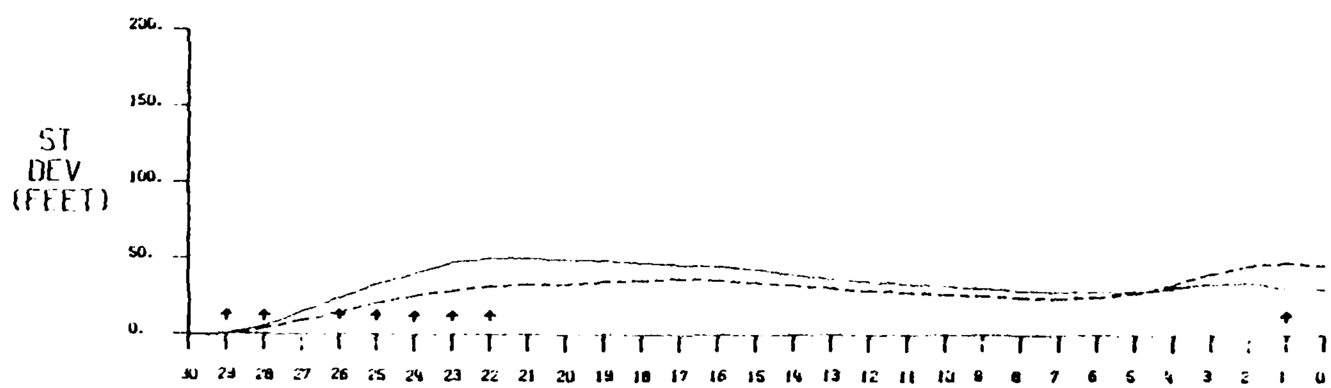




500 FT * CENTER * STAGGERED VS GATED





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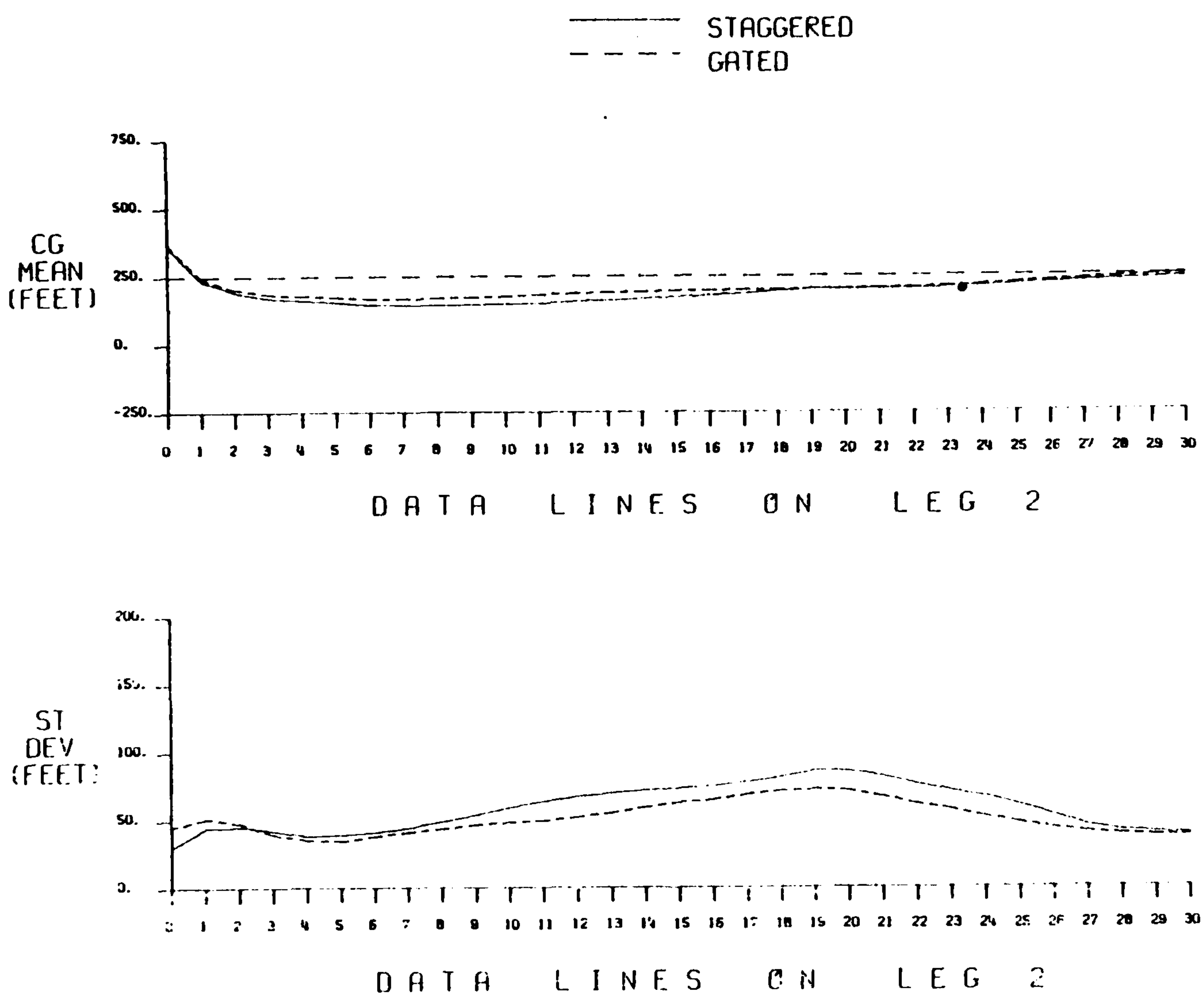
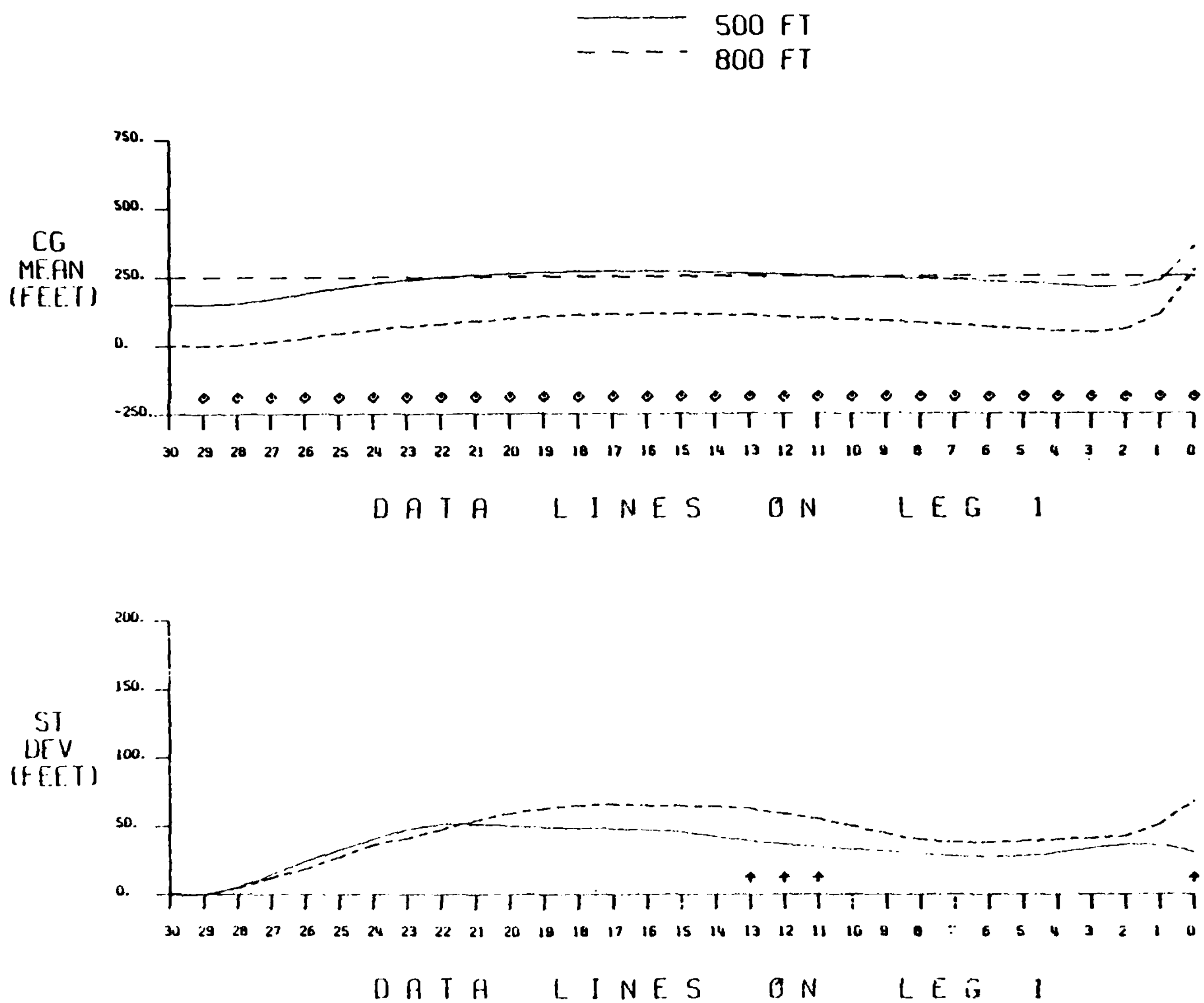


1 1/4 SPAC * CENTER * 500 FT VS 800 FT



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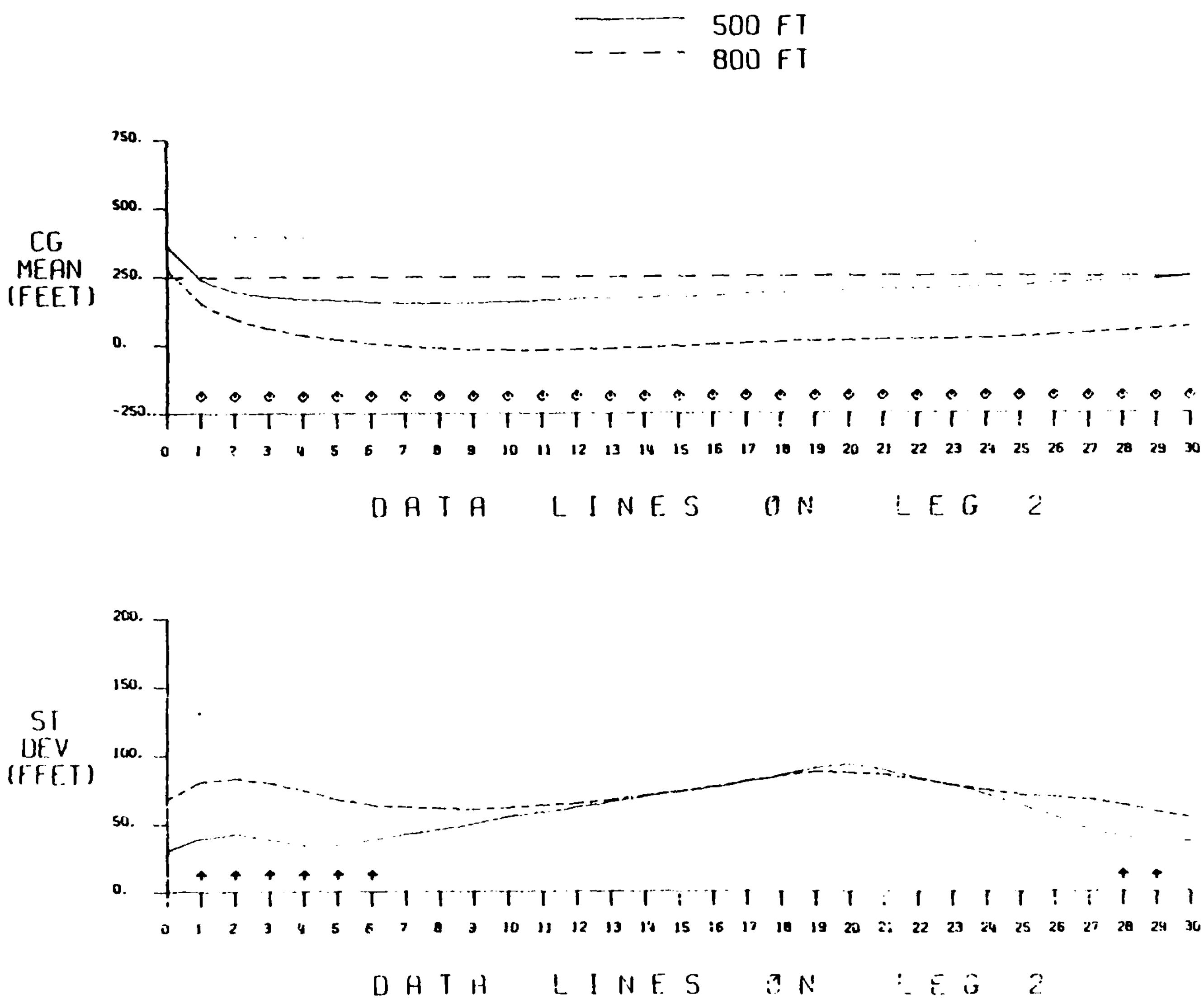

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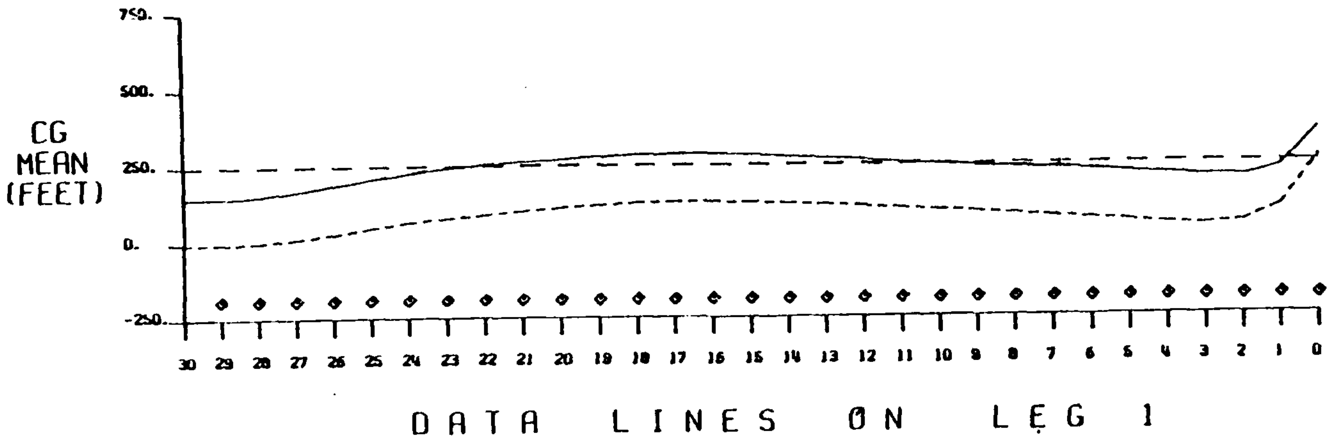

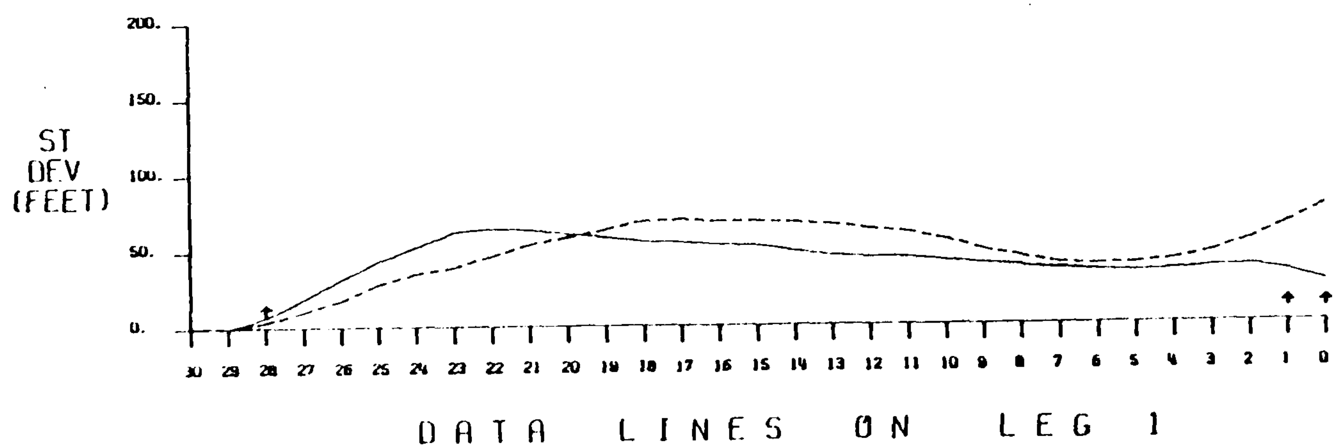

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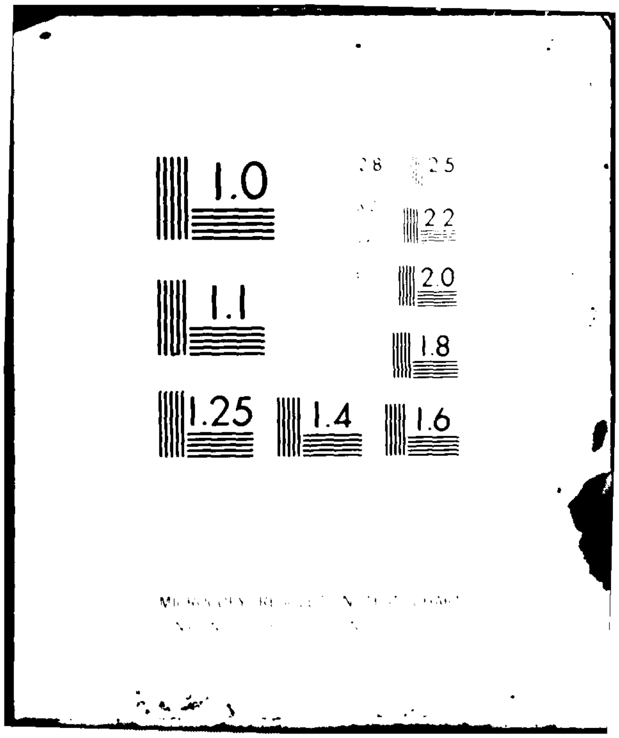
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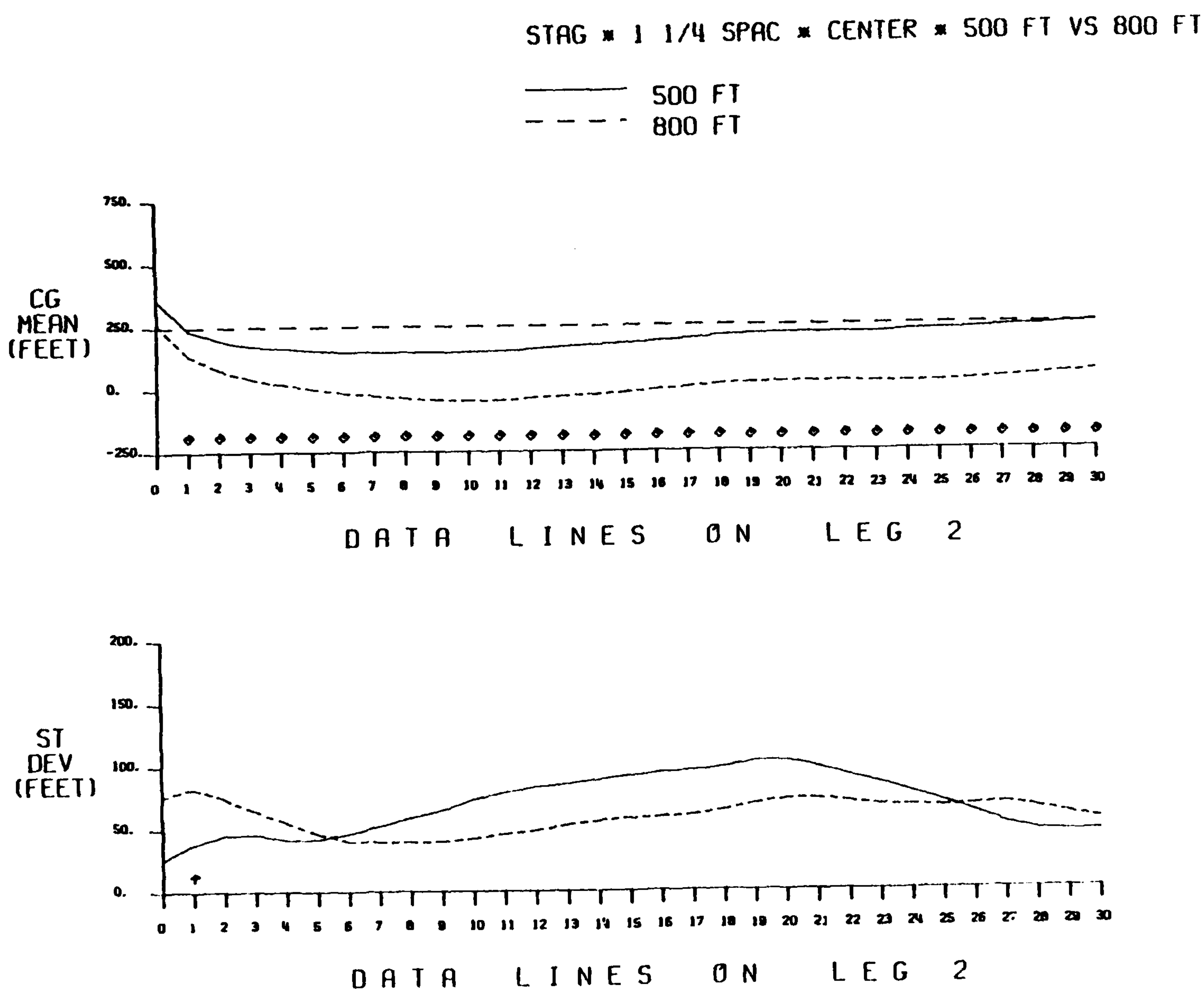
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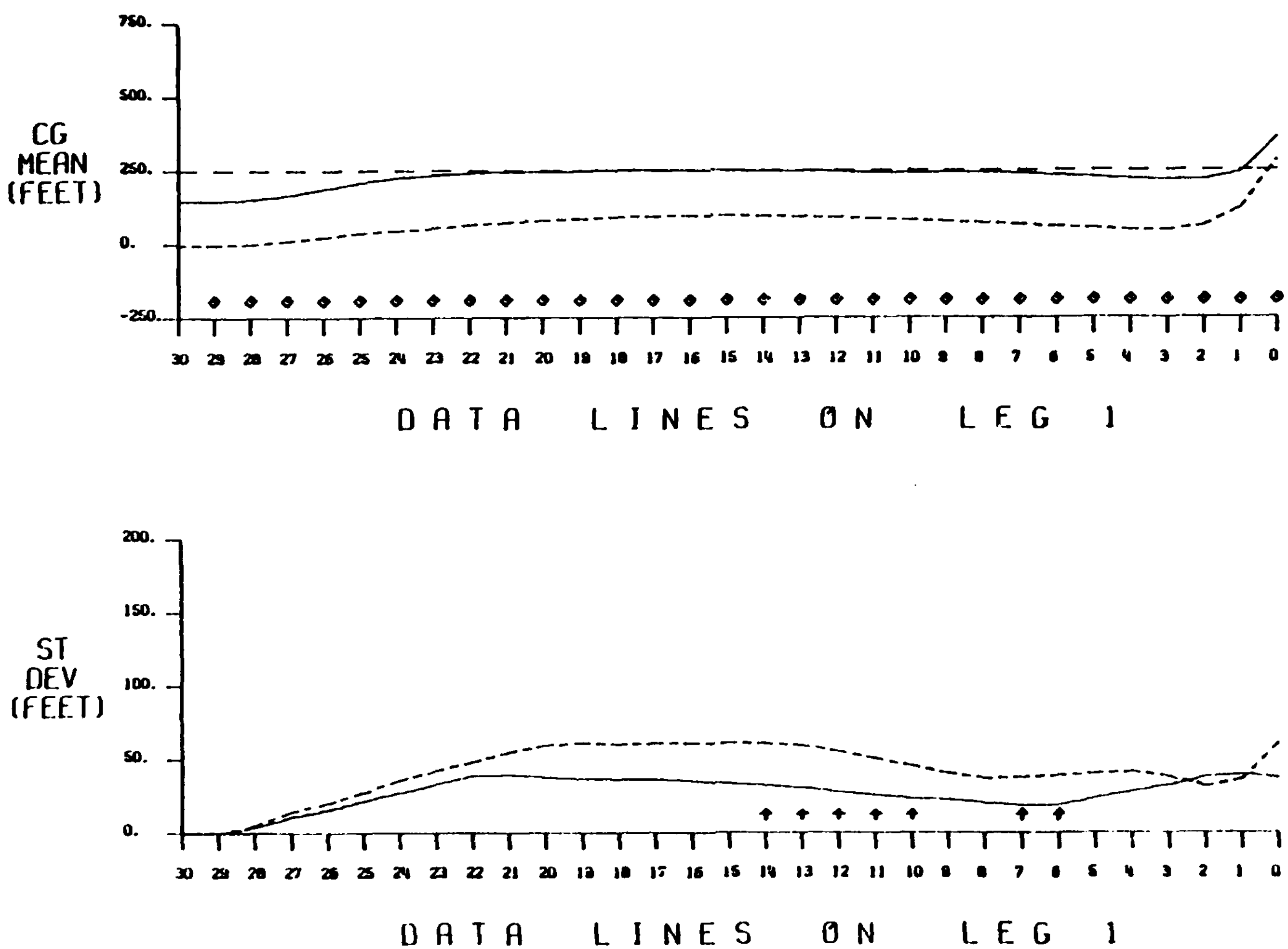
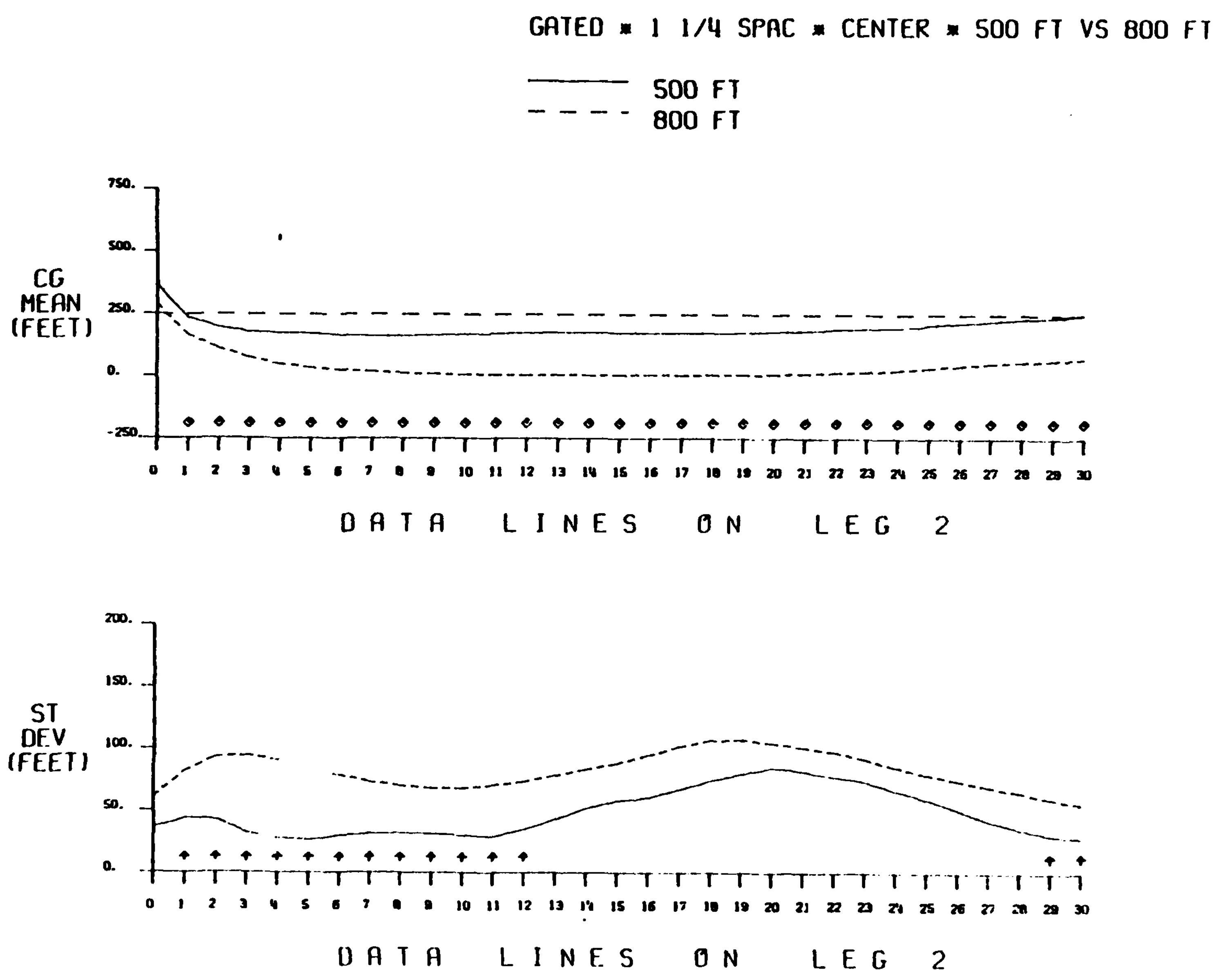
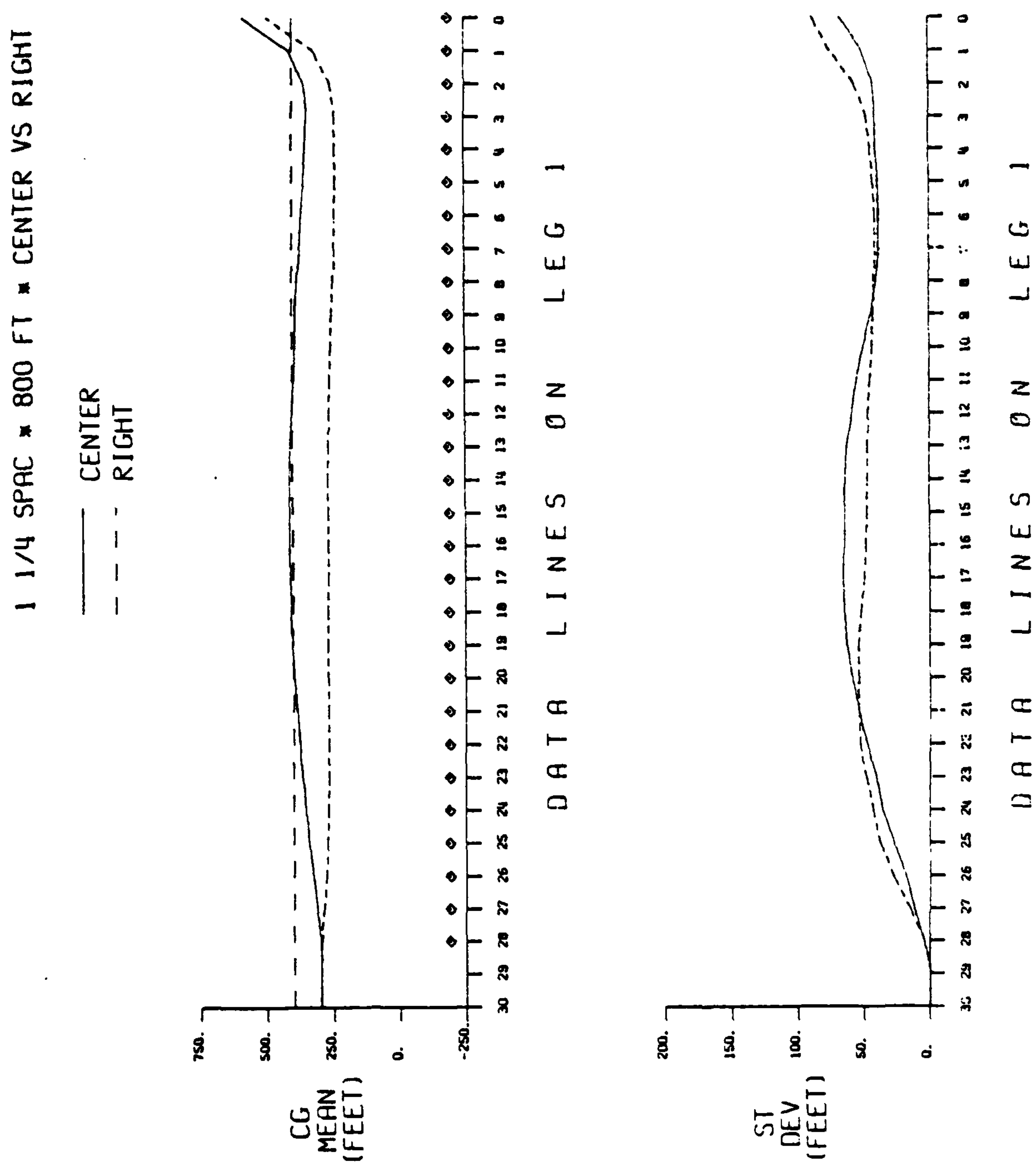
- - - 800 FT

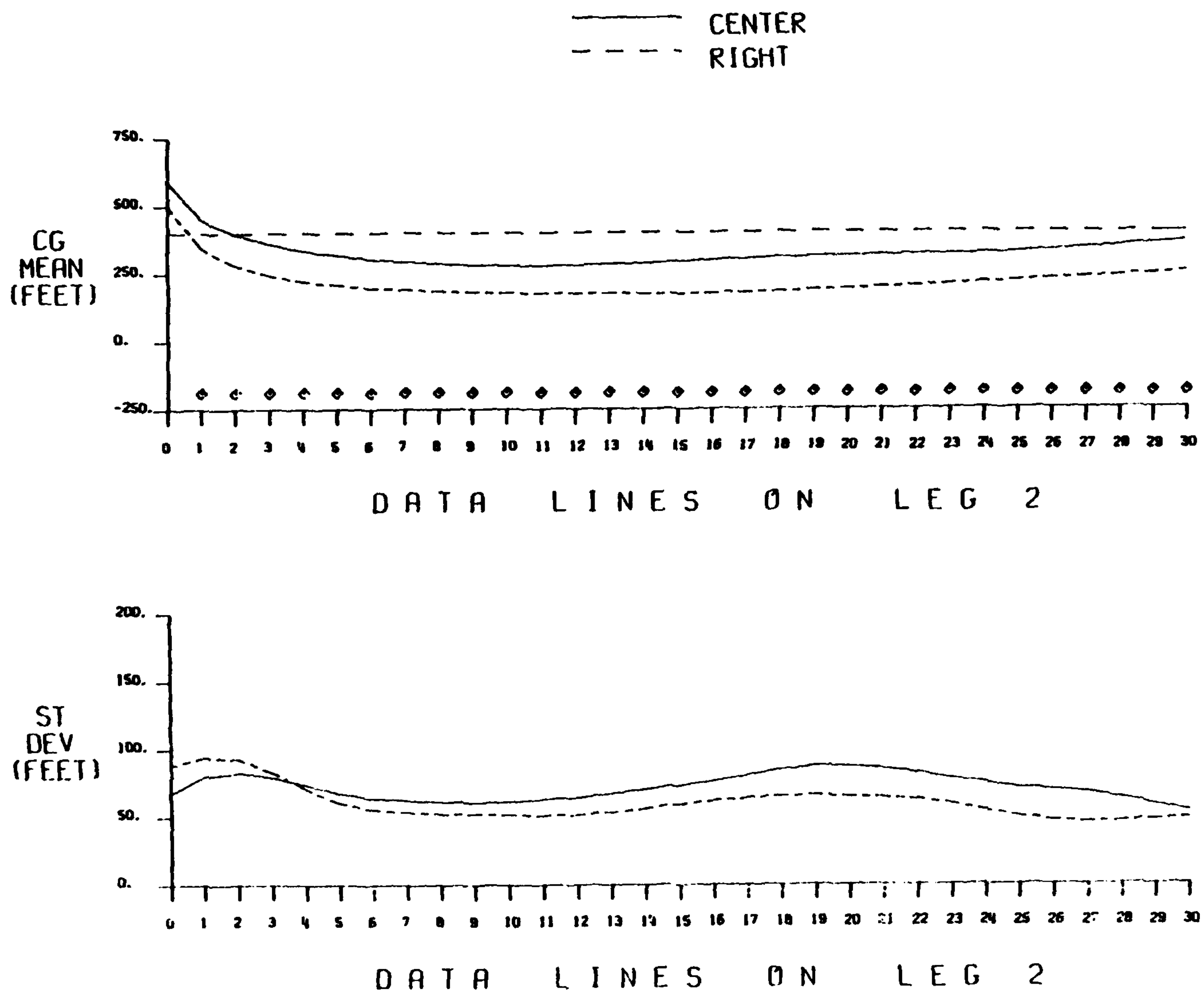




GATED * 1 1/4 SPAC * CENTER * 500 FT VS 800 FT
500 FT
800 FT
CG MEAN (FEET)
750.
500.
250.
0.
-250.
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
DATA LINES ON LEG 2
ST DEV (FEET)
200.
150.
100.
50.
0.
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
DATA LINES ON LEG 2

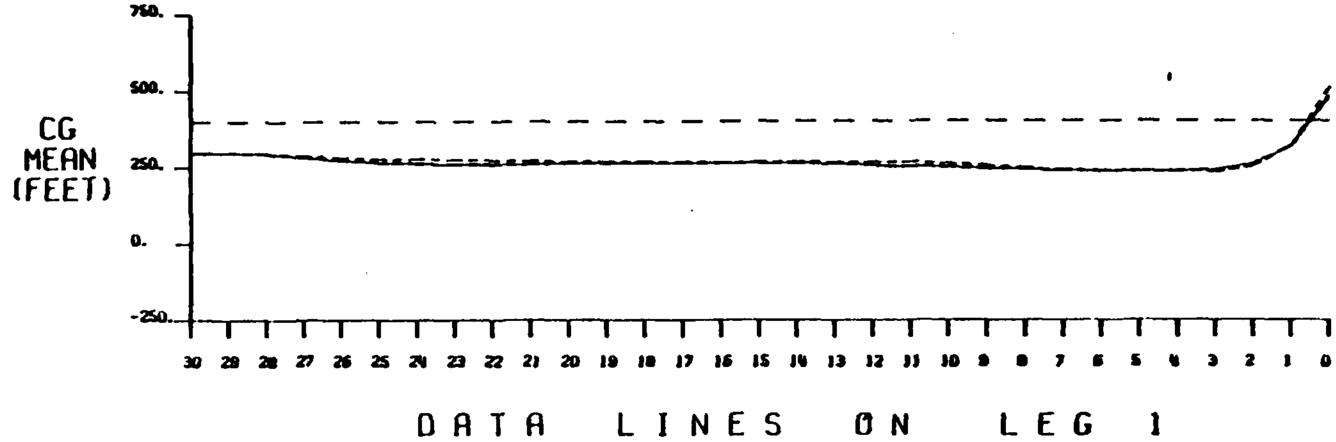

1 1/4 SPAC * 800 FT * CENTER VS RIGHT
CENTER
RIGHT
CG MEAN (FEET)
750.
500.
250.
0.
-250.
ST DEV (FEET)
200.
150.
100.
50.
0.
DATA LINES ON LEG 1
DATA LINES ON LEG 1

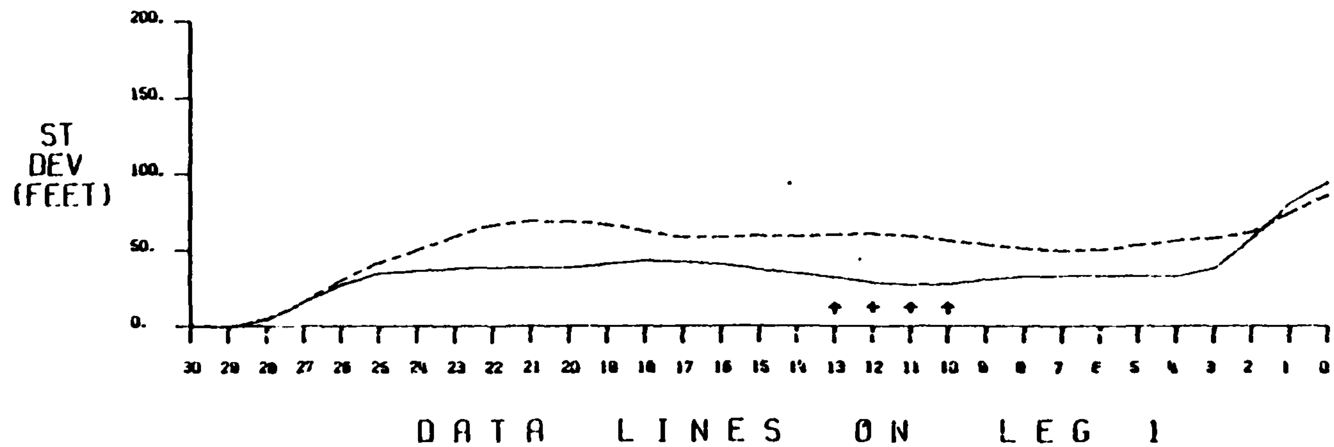
1 1/4 SPAC * 800 FT * CENTER VS RIGHT



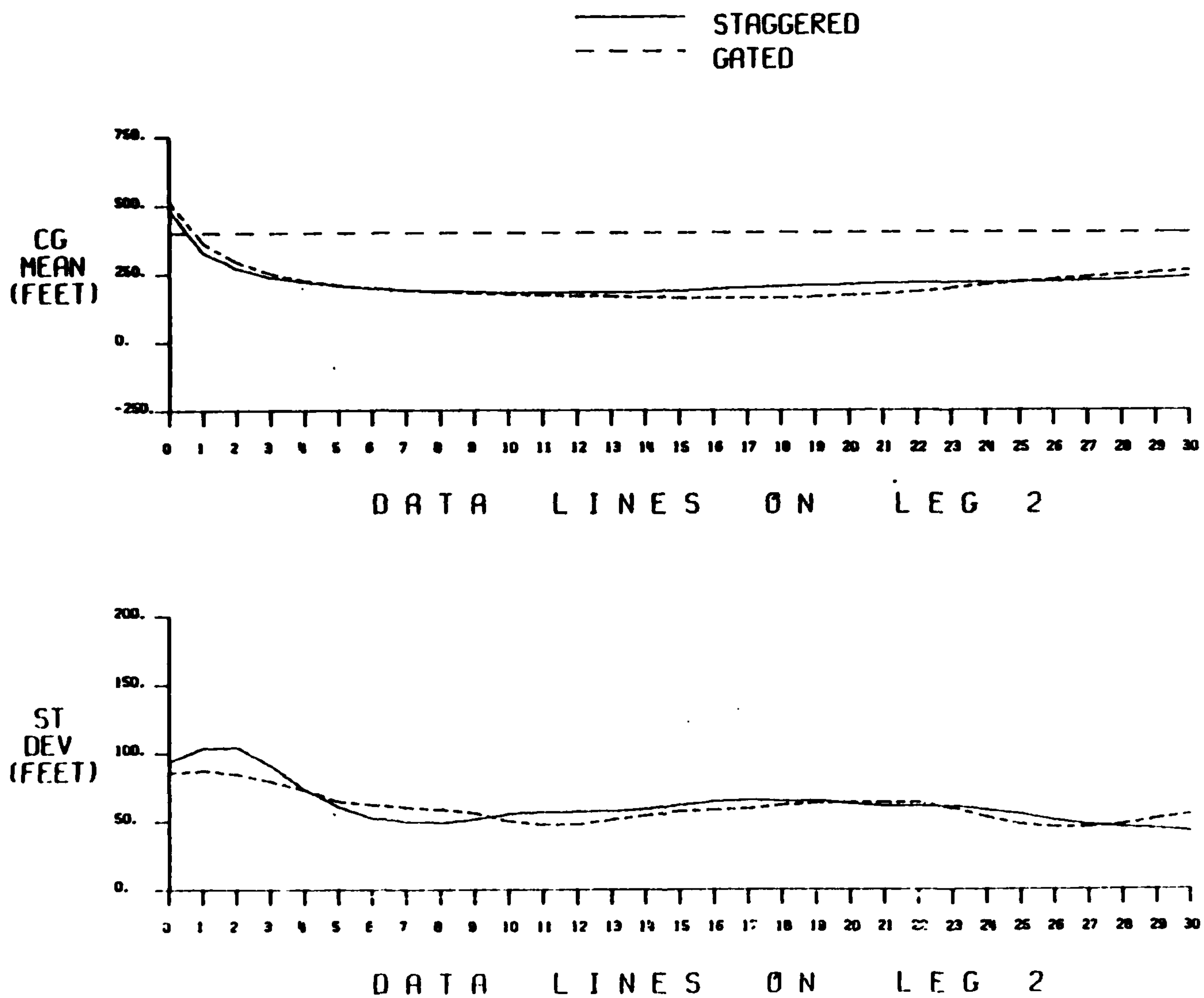
800 FT * RIGHT * STAGGERED VS GATED

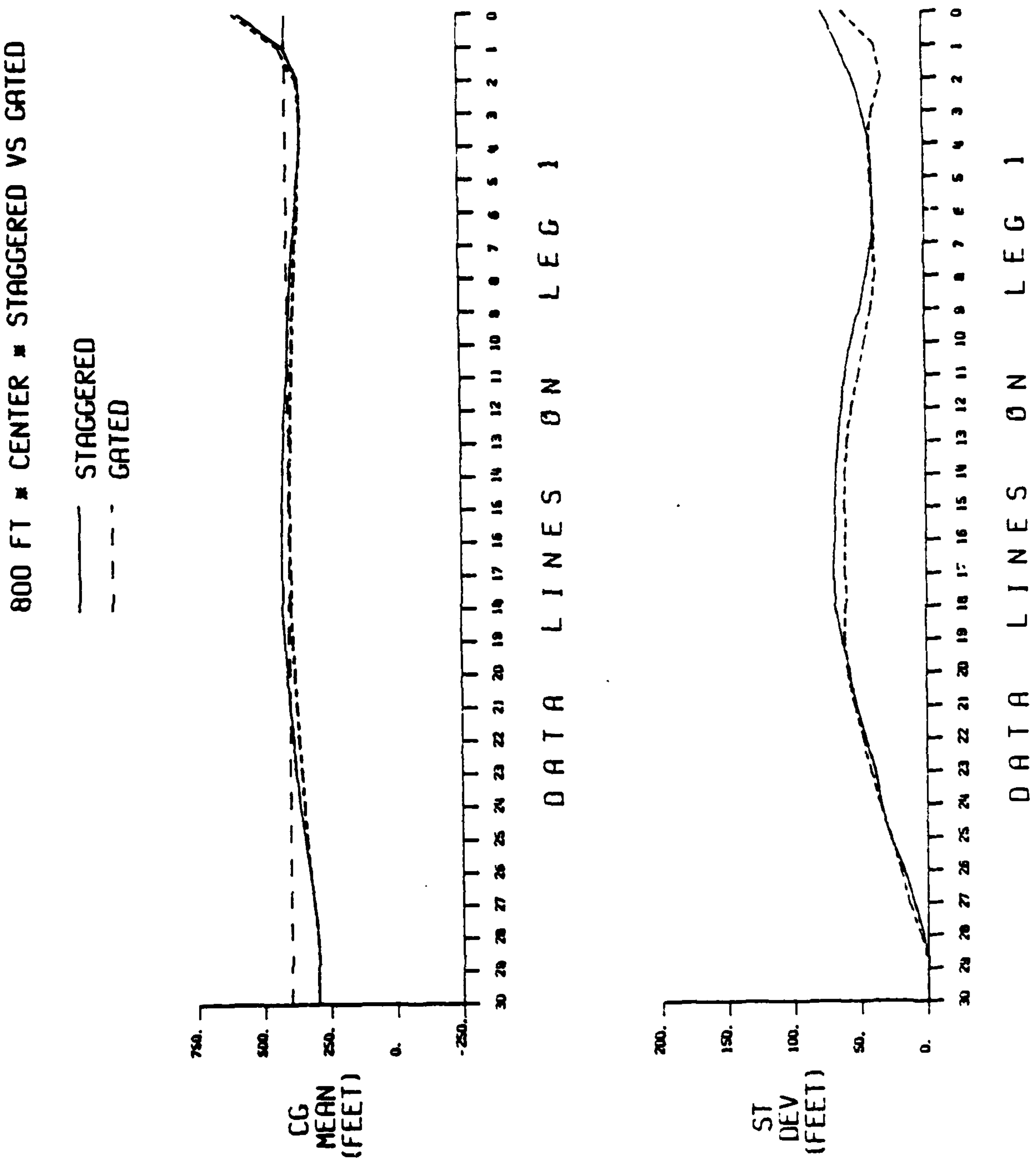
STAGGERED
GATED

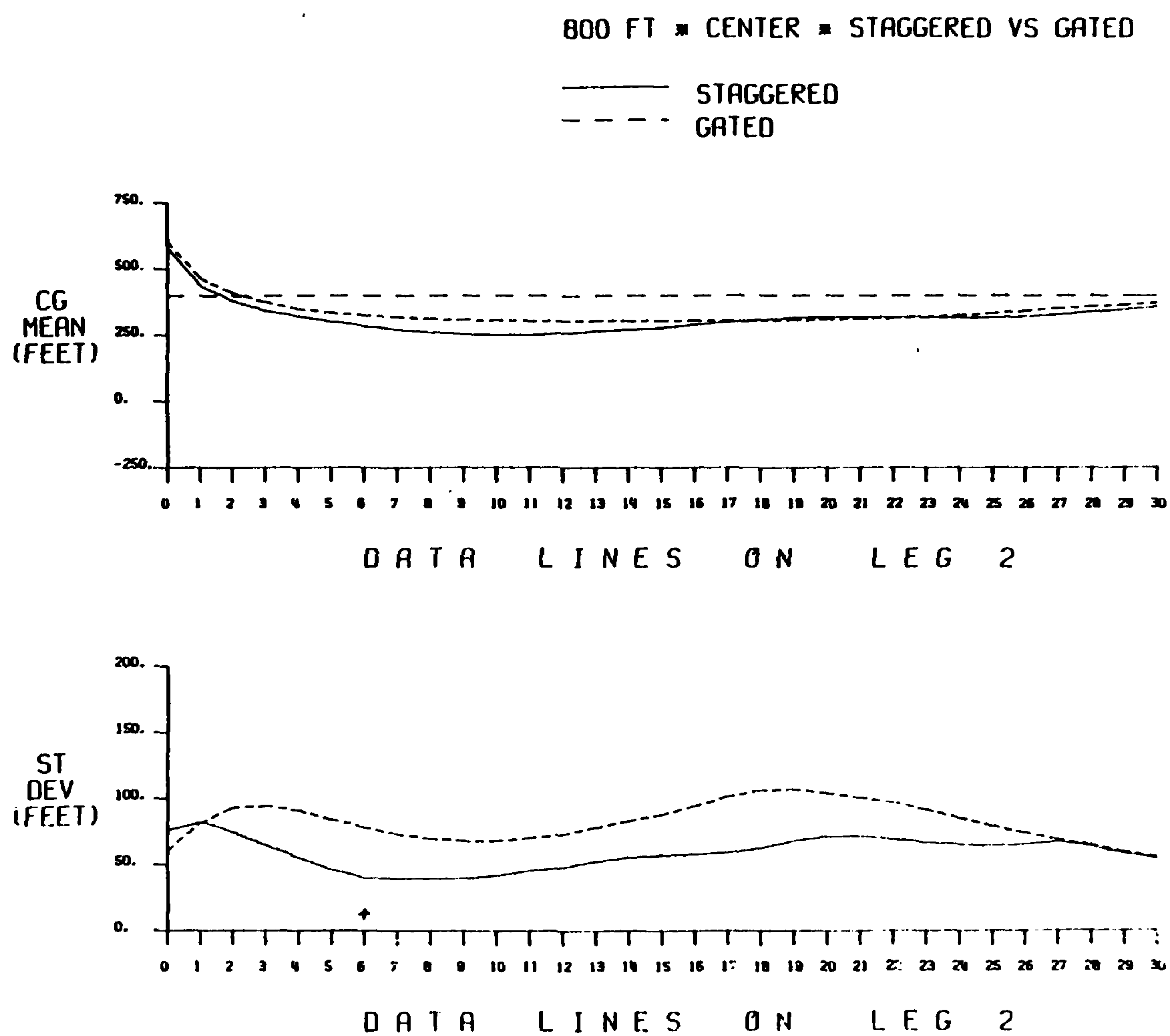




800 FT * RIGHT * STAGGERED VS GATED



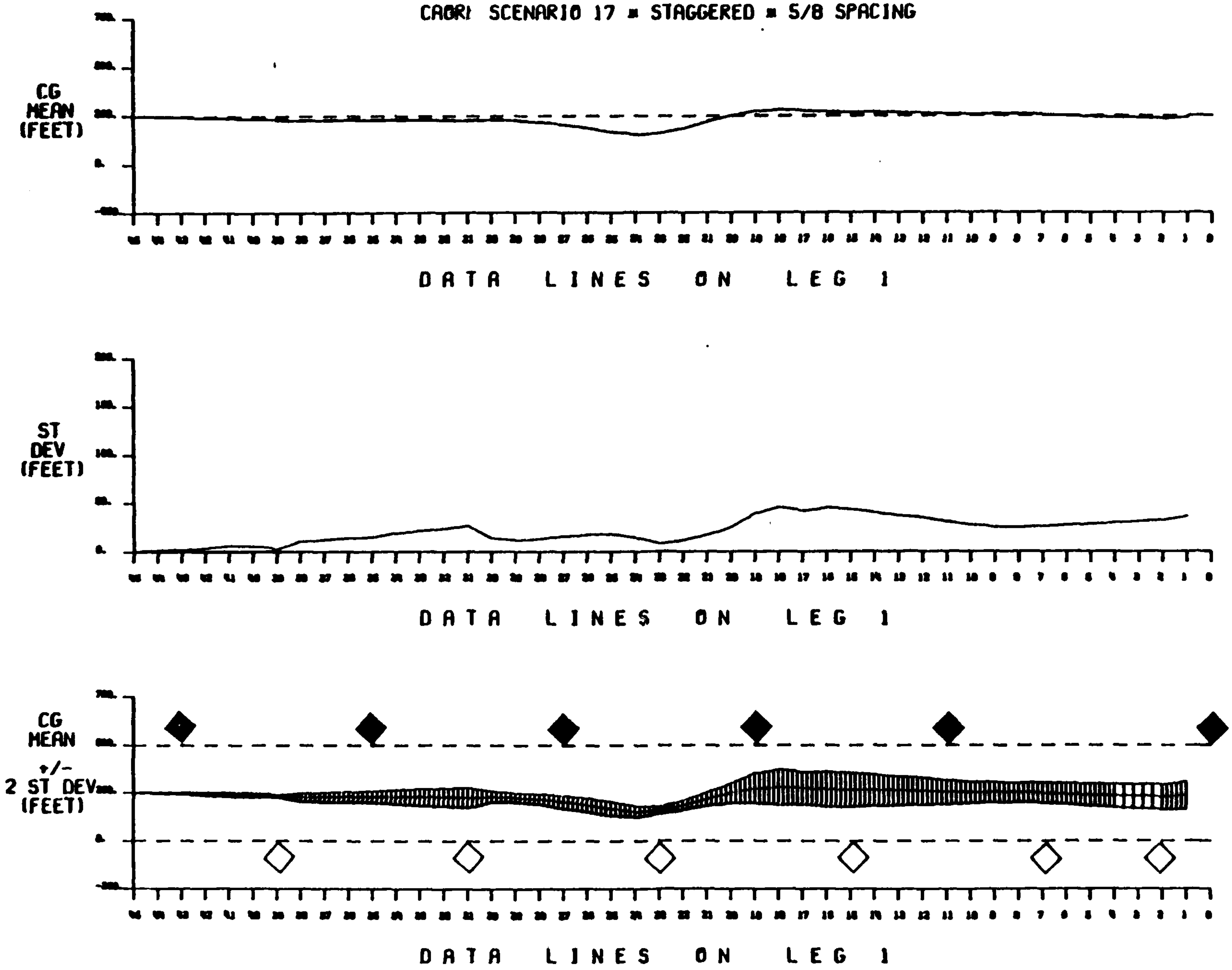

800 FT * CENTER * STAGGERED VS GATED
STAGGERED
GATED
CG MEAN (FEET)
750.
500.
250.
0.
-250.
DATA LINES ON LEG 1
ST DEV (FEET)
200.
150.
100.
50.
0.
DATA LINES ON LEG 1

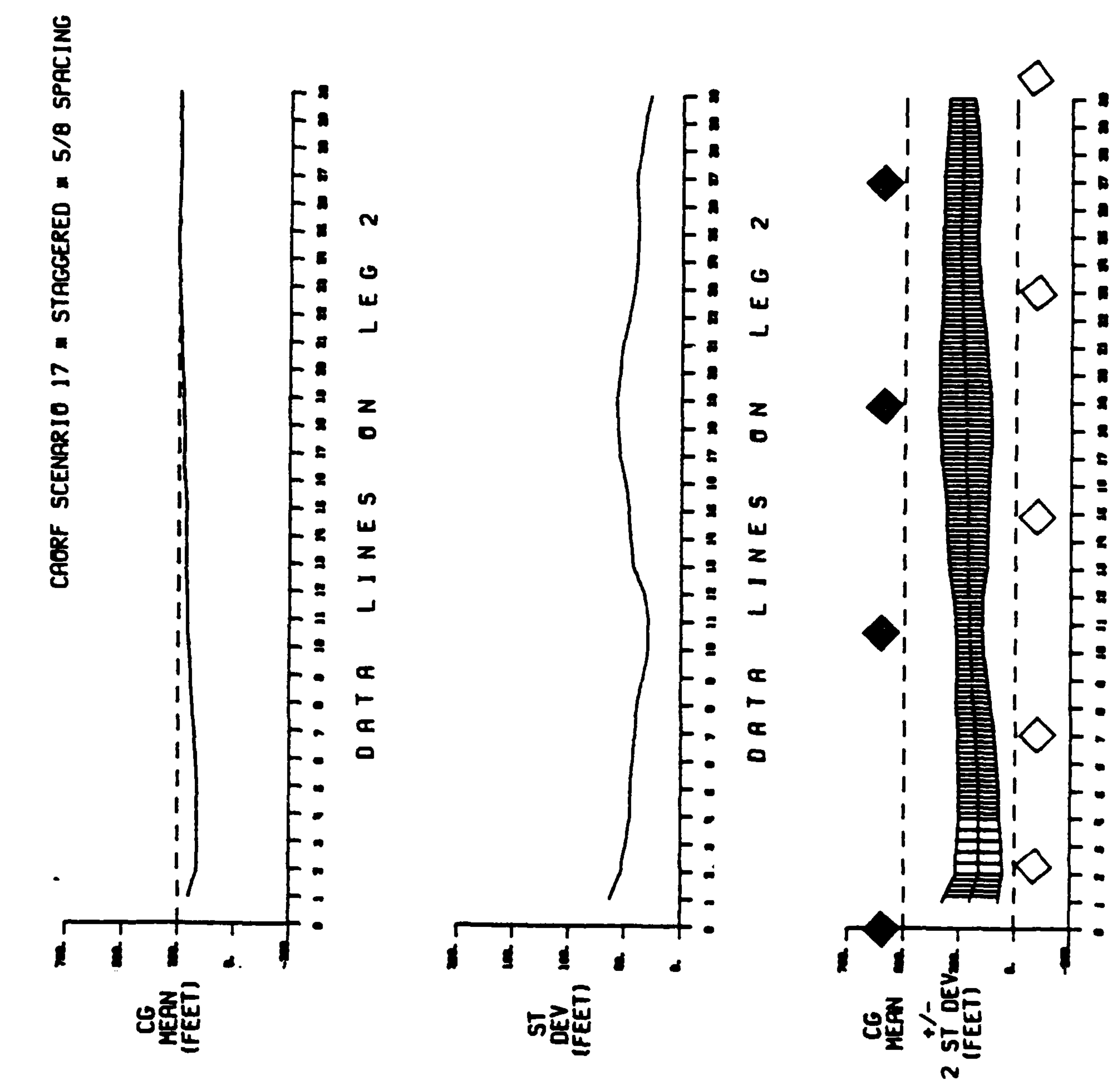

800 FT * CENTER * STAGGERED VS GATED
STAGGERED
GATED
CG
MEAN
(FEET)
750.
500.
250.
0.
-250.
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
DATA LINES ON LEG 2
ST
DEV
(FEET)
200.
150.
100.
50.
0.
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
DATA LINES ON LEG 2

APPENDIX E

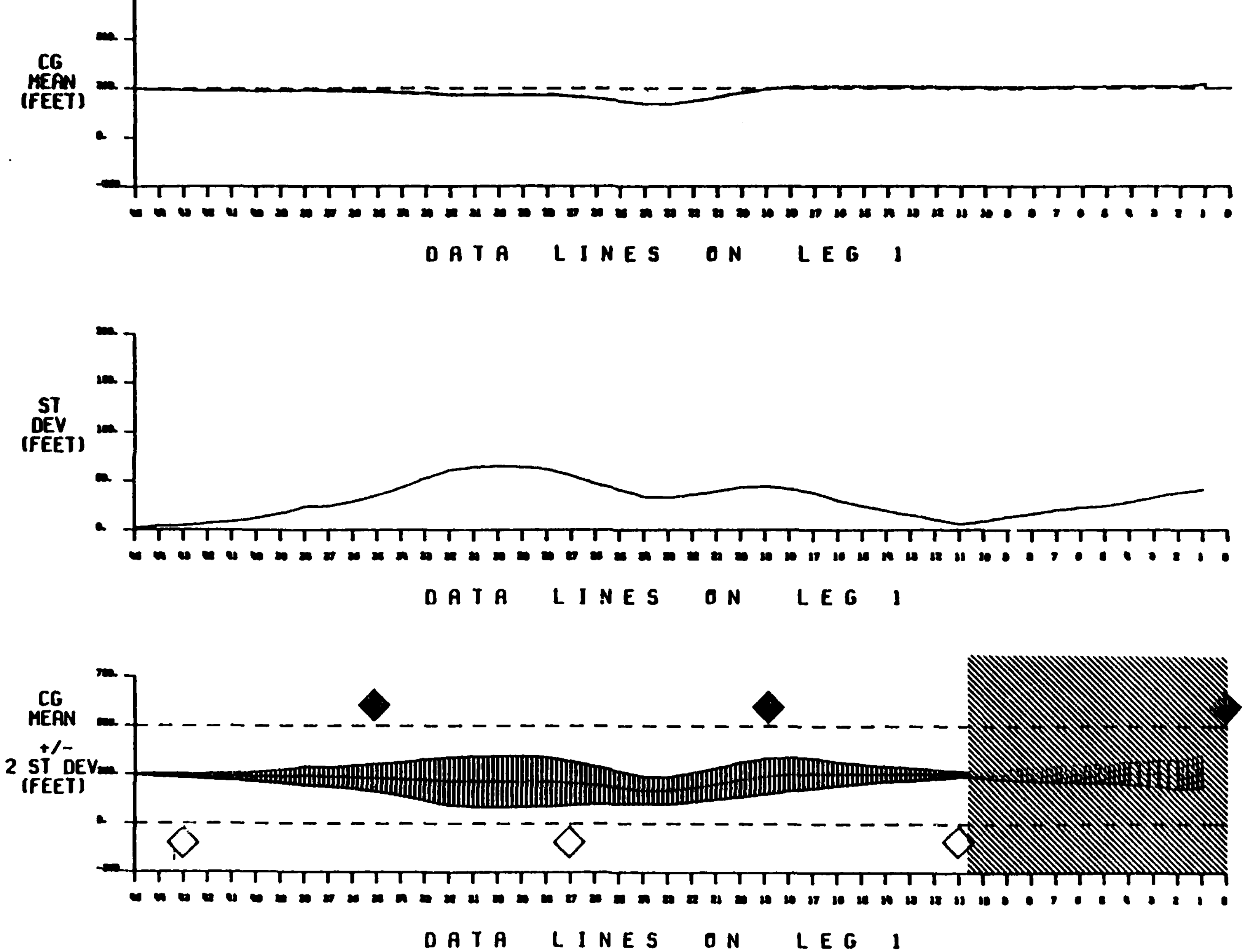
PERFORMANCE IN THE CAORF SCENARIOS CHOSEN FOR COMPARISON

CAORI SCENARIO 17 * STAGGERED * 5/8 SPACING

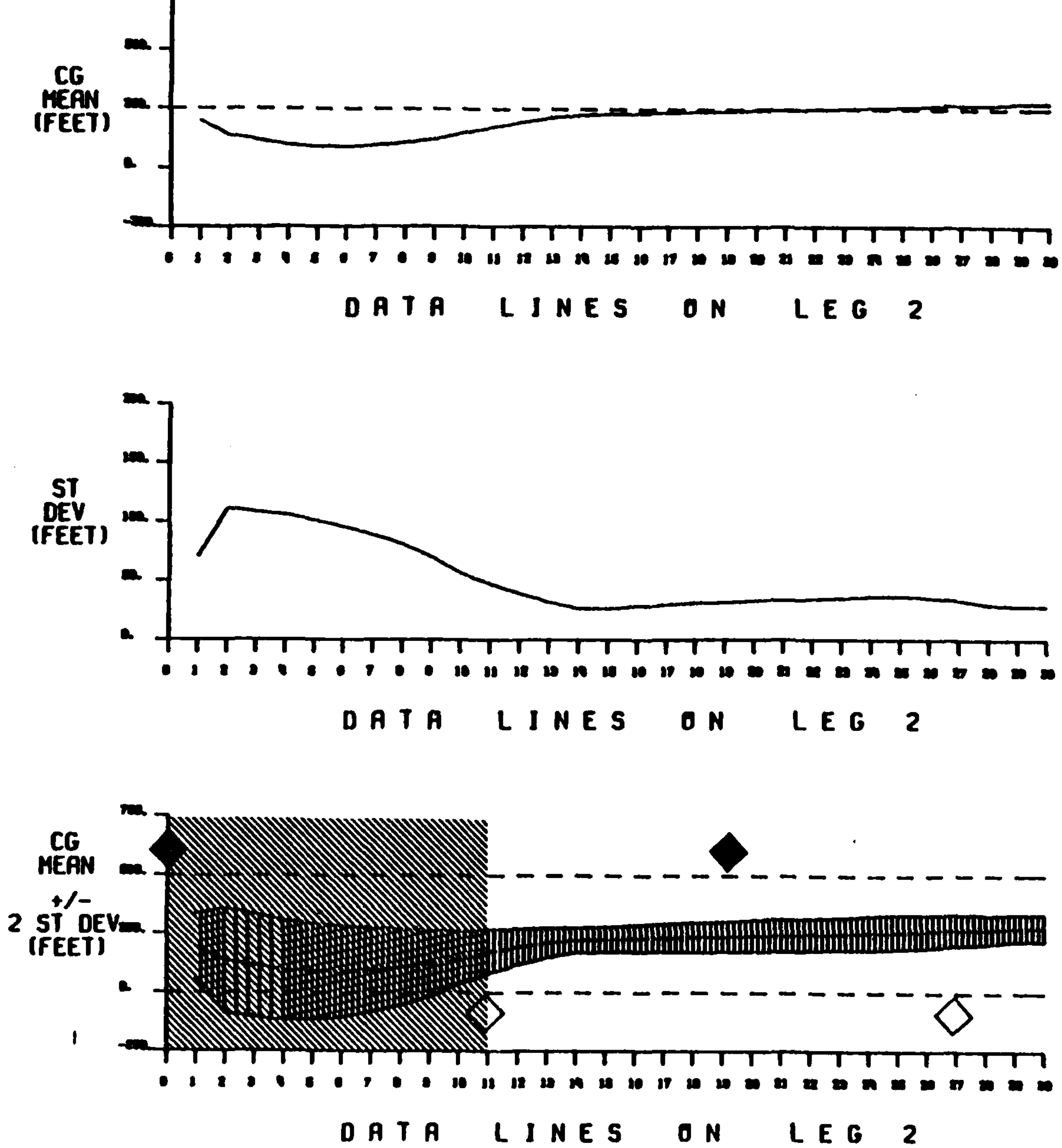


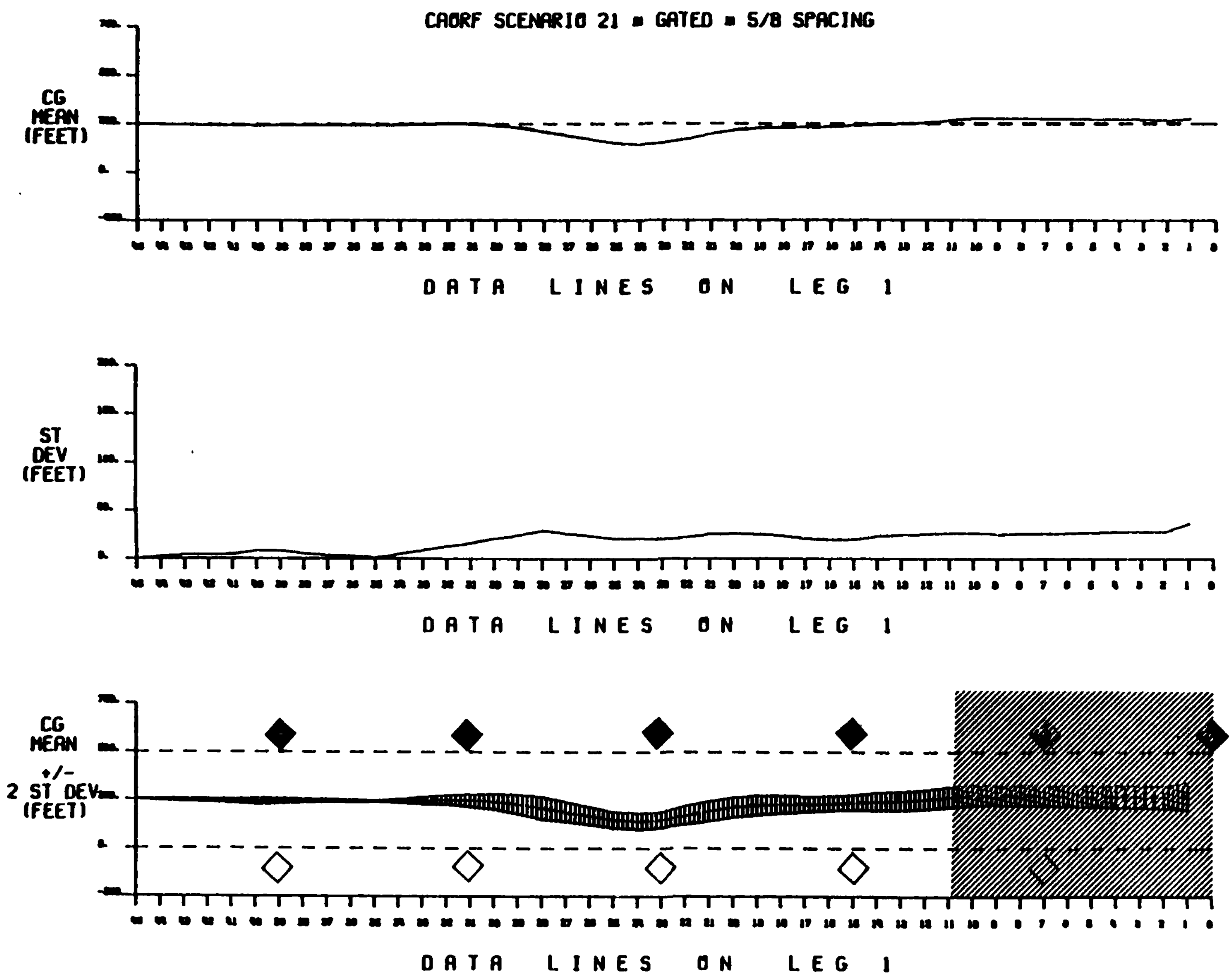

CAORF SCENARIO 17 * STAGGERED * 5/8 SPACING
CG MEAN (FEET)
DATA LINES ON LEG 2
ST DEV (FEET)
DATA LINES ON LEG 2
CG MEAN +/- 2 ST DEV (FEET)
DATA LINES ON LEG 2

CAORF SCENARIO 19 = STAGGERED = 1 1/4 SPACING

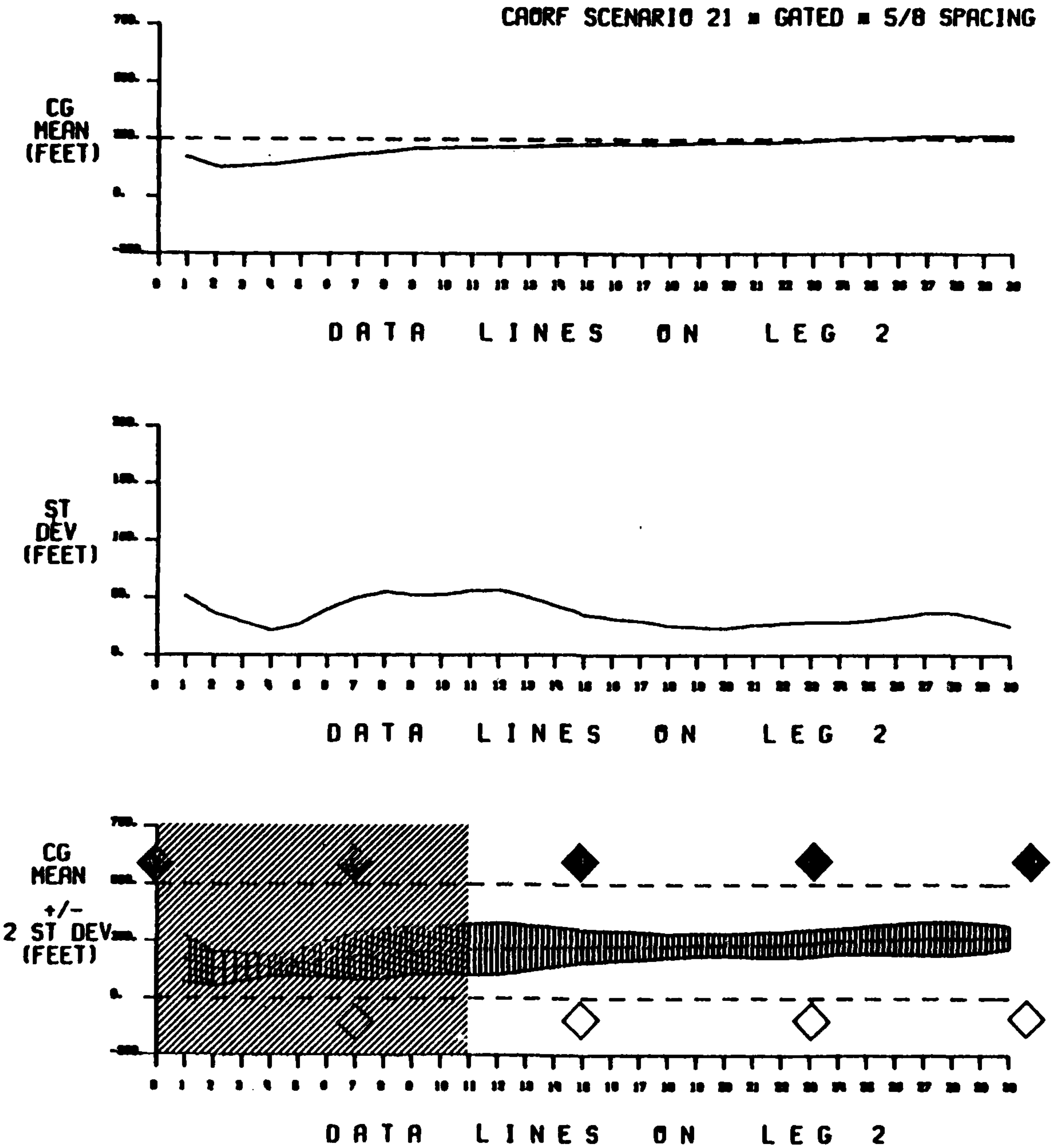


CAORF SCENARIO 19 = STAGGERED = 1 1/4 SPACING

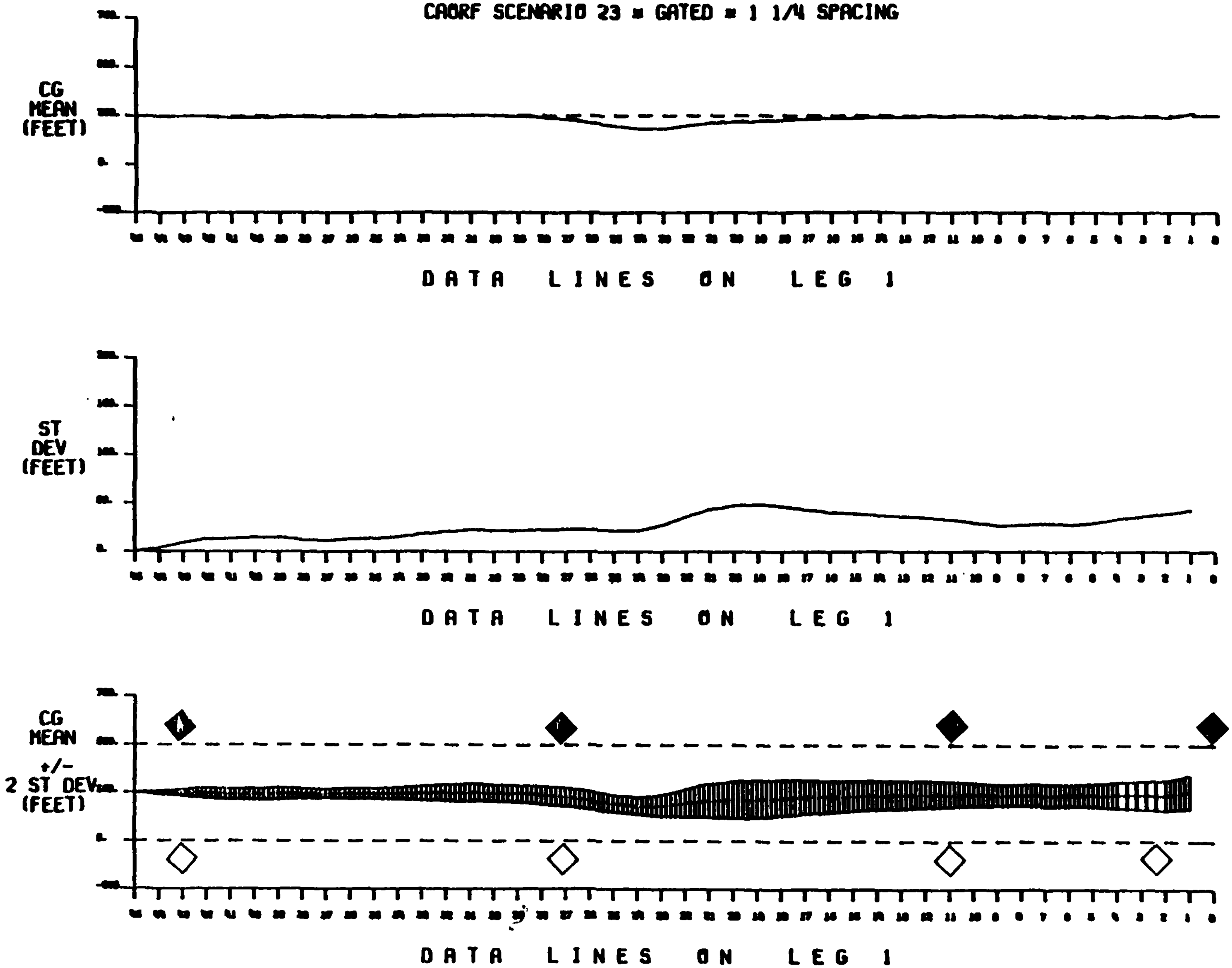


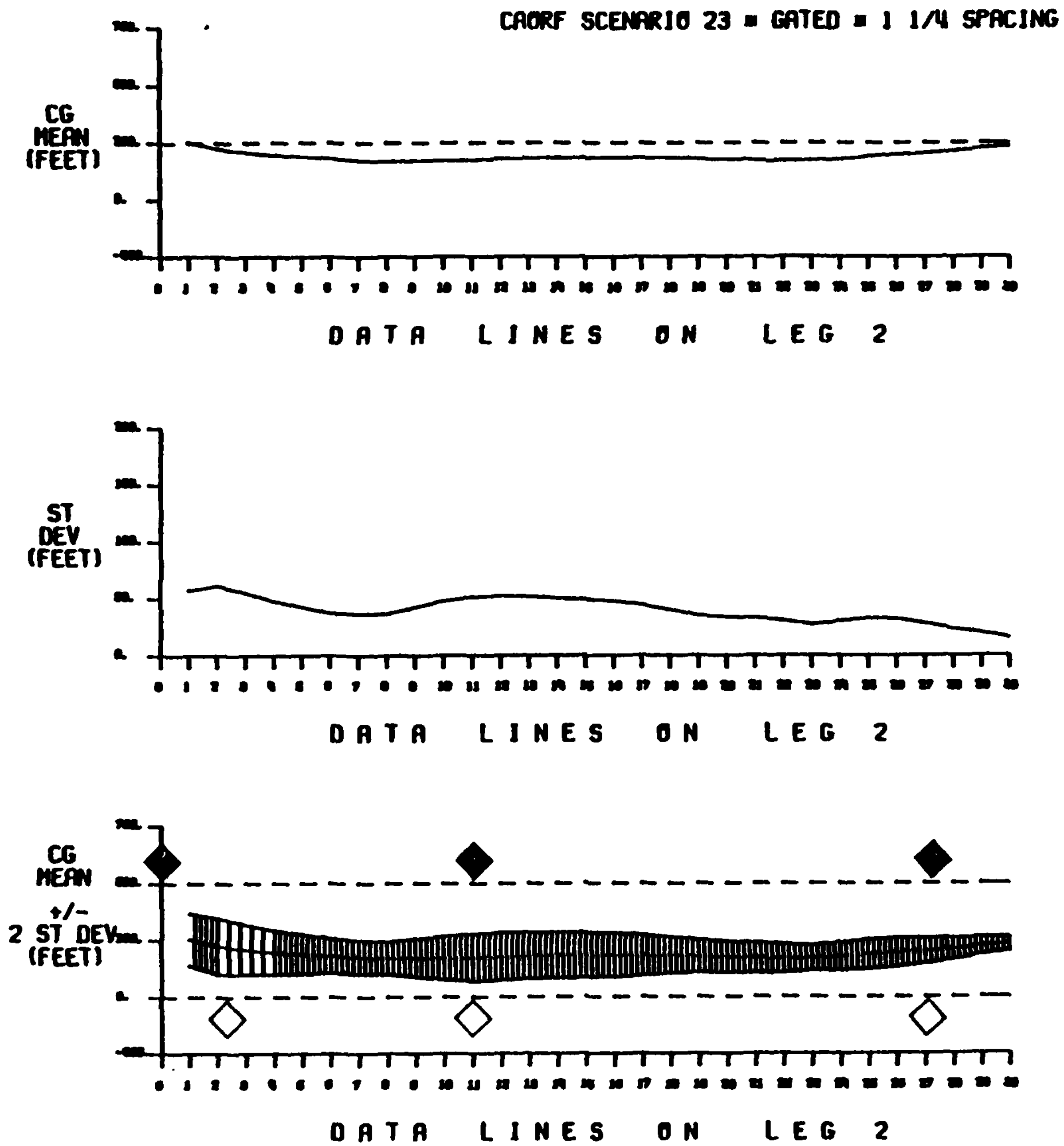

CAORF SCENARIO 21 = GATED = 5/8 SPACING
CG MEAN (FEET)
DATA LINES ON LEG 1
ST DEV (FEET)
DATA LINES ON LEG 1
CG MEAN +/- 2 ST DEV (FEET)
DATA LINES ON LEG 1

CAORF SCENARIO 21 = GATED = 5/8 SPACING



CAORF SCENARIO 23 = GATED = 1 1/4 SPACING





CAORF SCENARIO 23 - GATED - 1 1/4 SPACING
CG MEAN (FEET)
DATA LINES ON LEG 2
ST DEV (FEET)
DATA LINES ON LEG 2
CG MEAN +/- 2 ST DEV (FEET)
DATA LINES ON LEG 2

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